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A novel method of measurement of loss in a track of a turn of a planar transformer for induction heating applications

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ABSTRACT

The new trend in power converters is to design planar magnetic components aimed at low profile. However, at high frequencies, the AC losses induced in the planar inductor and transformer windings become significant due to skin and proximity effects. This paper presents the design of a high-frequency planar transformer (HFPT) for an induction heating system. The aim of this design is to adapt the levels of voltage and current from the inverter to the resonant tank characteristics. We propose a planar structure of Litz in the primary of our HFPT to reduce the AC resistance of the planar conductor. The Litz structure is obtained with a technique of the turn's division in four tracks and their intersection so that the current passes all over the turn.

For the single secondary turn, the choice of the section is based on an analytical study compared to a 2D finite element modeling (FEM), and is determined according to the shape that represents fewer losses and responds to our needs.

2D finite element modeling (FEM) was performed for three different primary turns' structures; full coil, a turn with four parallel tracks and our Litz planar turn; to minimize losses. Simulation results show that the planar Litz conductor can lead to a lower AC resistance. The performance of this Litz structure is also verified by measurements on experimental prototypes.

1. Introduction

AC Winding resistances depend on both the operating frequency and the winding configuration. At high operating frequencies, the current through a solid wire concentrates along the conductor edges, due to the skin and proximity effects Ref. [1].

HFPT are largely used in many electrical and electronic designs. Switching at higher frequencies is an interesting option to reduce passive components and isolation transformers. In addition they allow adapt different levels of voltage and provide electrical and galvanic isolation between both windings. However, there is not a standardized procedure for design transformers, and every manufacturer keeps their method confidential. An optimized design can save power, volume, weight and money for both manufacturer and customer. Most of researches have been studied the theory of HFPT and its usage in power systems Ref. [2,3].

In this paper, the principle of Litz conductor is applied to planar conductor. The literature has already shown that this technique leads to a reduction in the equivalent AC resistance.

In Ref. [11] work was examined on high levels of power and realistic operating conditions, in combination with calorific measurements. Several configurations of Litz interconnections are investigated. These include 90 and 120 track angles, wide and narrow tracks, and parallel track structures with only one track crossing. It is shown that the latter performed very well under high power conditions.

A planar Litz structure is showcased in Ref. [10], aiming to reduce the high-frequency losses in planar windings. This planar Litz type conductor is constructed by weaving many narrow strands along the length of the conductor in such a pattern that each strand can be subjected to every point of the winding cross sectional areas. Thus, the current is distributed uniformly on the conductors. The measured results showed that the reduction of AC resistance by using Litz winding instead of solid conductor could be as high as 30%.

Ref. [7] proposes a manufacturing technique and loss analysis model for PCB windings using the planar Litz structure to obtain a loss reduction of AC power similar of conventional windings of

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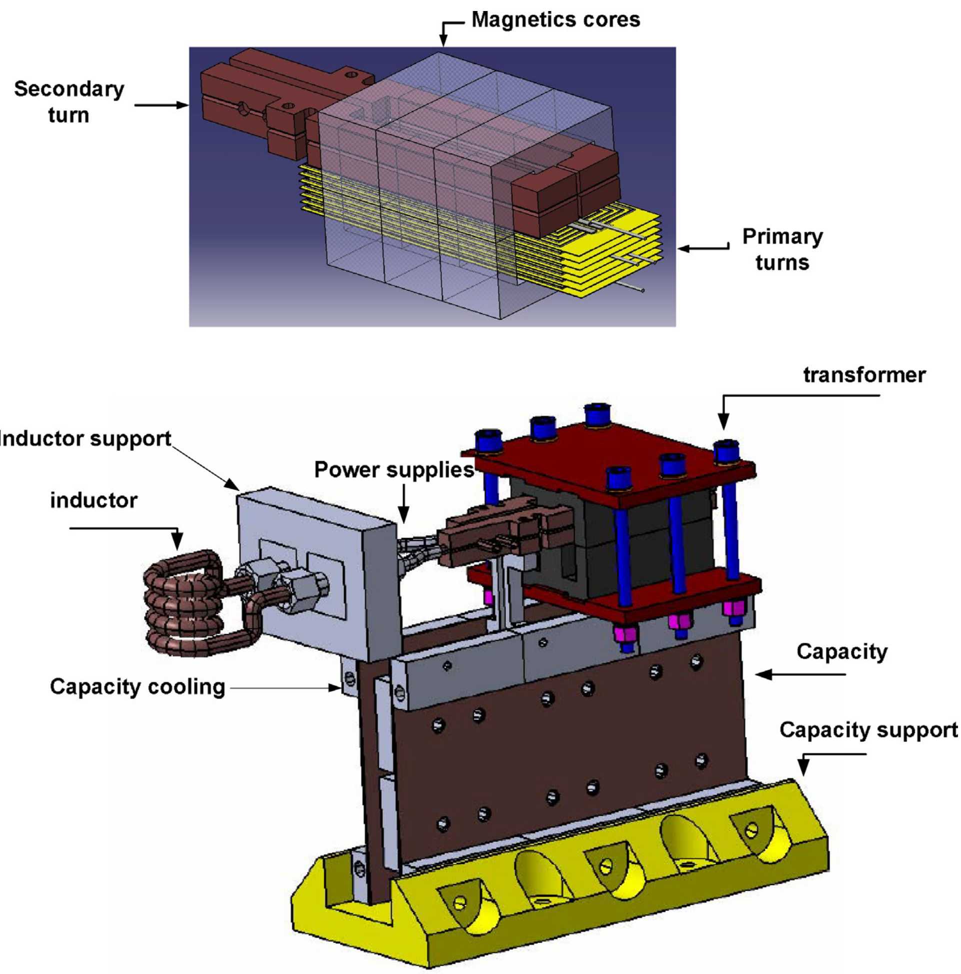

Fig. 1. Planar transformer.

Table 1
Characteristics of our transformer.

Variable	Value	Unit
Primary voltage RMS	320	V
Secondary voltage RMS	22	V
Secondary current RMS	304	A
Primary current RMS	21	A
Resonant frequency	100	kHz
number of primary turns	14	turns

round wires with Litz structure. Different prototypes coils were tested in several configurations to validate the proposal. A losses method calculation is proposed for the implementation of multi-planar multi-PCB coils. A simplified method is presented based on the calculation of the field in a coil with one track. Resistance expression of a winding is provided, including the shape of the track and the working frequency.

A PCB implementation of planar windings replicates the structure of conventional Litz wires in order to reduce the AC losses. This structure consists of a set of fine traces electrically connected in parallel which are transposed by means of changes in both trajectory and layer. An appropriate transposition strategy is essential to reduce the winding AC losses, however PCBs with high number of vias prove expensive and unreliable Ref. [8].

In this paper, a HFPT for induction heating device is presented, thus its losses analysis. This HFPT has been designed in order to adapt the voltage and current levels between the converter and the resonant tank Ref. [13,14]. To achieve our HFPT, the choice and sizing of the primary and secondary of the transformer are necessary. Simulations followed by experimental results were done to calculate losses in one turn of the primary of our HFPT. We compared different structures of the primary turn: full turn, a turn with four parallel tracks and a Litz planar turn. For the choice of the section of our single secondary turn, analytic and 2D finite element modeling was done.

2. Losses analysis of high frequency planar transformer

2.1. Characteristic of planar transformer

The planar transformers are constituted of a magnetic circuit (usually ferrite) in which one inserts a printed circuit (multi-layer PCB) on which the whorls are engraved, Fig. 1.

The technology of printed circuit makes it possible to obtain drivers reduced thicknesses. Table 1 shows the characteristics of our transformer.

This planar transformer is used in a half bridge converter and its associated voltage and current waveforms are shown in Fig. 2. The voltage across the primary winding is a square wave with peak values of $-\frac{560}{2}$ V and $\frac{560}{2}$ V. The current through the primary winding is also sinusoidal with peak values of −38A and 38A Ref. [15,16].

Our induction heating is modular and can operate at a power of 5 kW and a power of 10 kW when operating the two modules.

When power converters operate at high frequency, the design difficulty for the transformer becomes much higher. The current