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Determination of Winding Losses of Low-Profile Planar-Type Transformer

C.F. Foo and X.H. Gong

School of Electrical and Electronic Engineering, Nanyang Technological University, Nanyang Avenue, Singapore 639798

Abstract. At high frequency, the winding losses of power transformer due to skin and proximity effects becomes a significant component in the loss calculation of the transformer efficiency. This paper examines the winding losses associated with these effects for planar-type low-profile transformers that are suitable for high frequency high density soft switching power supply application. The transformer winding ac resistance and leakage inductance are investigated for the different winding arrangements. 2D and 3D Finite-element methods are used to study the magnetic flux distribution in the transformer window area and the current density distribution in the winding conductors.

1. Introduction

In the design of high frequency soft switching power supply, high efficiency and miniaturization of power transformer are desirable to achieve effectively higher power density for the converter. Recent literatures on the transformer design have been concentrated on minimizing the winding losses and the core losses of the wound winding and spiral winding transformers[1,2]. Planar-type transformer has better electrical characteristic with its special planar winding configuration. It is a suitable choice for the high frequency ZVT-PWM DC-DC converter[3] for its lower profile structure, smaller winding losses and leakage inductance.

The purpose of this paper is to examine the winding losses of planar-type transformer associated with skin and proximity effects at high frequency using Maxwell[4] CAD program. Using planar winding configuration effectively reduces skin and proximity effects in the winding conductors. The study indicates that such a configuration reduces the non-uniformity of current density distribution in the winding conductors; hence decreases the winding ac resistance to give low winding losses. Compared with non-interleaving winding arrangement, interleaving results in a smaller ac resistance and lower winding losses. In addition, it results in a smaller winding leakage inductance with higher flux coupling. The study serves as a guideline on how to reduce skin and proximity effects and winding losses so as to achieve higher transformer efficiency.

2. Simulation study

At high frequency operation, skin and proximity effects cause the ac currents in winding conductors to flow non-uniformly near the surface of the conductor. This non-uniform distribution results in the increase of winding ac resistance. Both effects increase with frequency, causing additional losses to the transformer. Two winding arrangements are considered in this study.

A planar-type transformer MTC-T050[5] with a planar winding configuration is considered in this study, as shown in Fig.1. An insulator layer is placed between every two winding layers and a separation of 0.5mm is between every two wires in each winding layer. The foil coil is 0.5mm×0.035 mm, and the insulator is 0.03 mm thick. The spacing in this winding configuration effectively reduces the proximity effect in the winding conductors. Since high frequency current flows along the side of the conductor due to skin and proximity effects, the foil conductor with a skin depth thickness is sufficient for the transformer to operate at very high frequency. Two different winding arrangements are considered here.

Fig. 2(a) and (b) illustrates the current density values along the lines in the center of the fourth winding layer with non-interleaving and interleaving winding arrangements respectively. The input source current is 1A, the operating frequency is 500kHz. In non-interleaving configuration shown in Fig.1(a), the current density is concentrated near both sides of conductors with the peak value more than $1.0 \times 10^6 \text{ A/m}^2$ while the value at the center of the conductor is near zero. This is due to the field non-uniformity arising from skin and proximity effects. In the case of the interleaving winding shown in Fig.2(b), the peak current density at the sides of conductors is reduced to $9.0 \times 10^5 \text{ A/m}^2$ while the value at the center of conductor is $8.5 \times 10^5 \text{ A/m}^2$. Interleaving winding arrangement greatly reduces the non-uniformity of current density distribution. The corresponding winding losses P_d are shown in Fig.3. The losses associated with interleaving is smaller than that with non-interleaving. At 500kHz[3], P_d is reduced from 43.52 mW to 23.32 mW. Interleaving winding arrangement results in reduced winding losses because of the reduced skin and proximity effects.

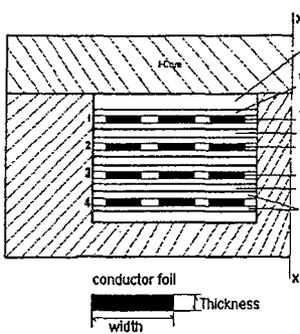


Fig.1 Planar winding configuration

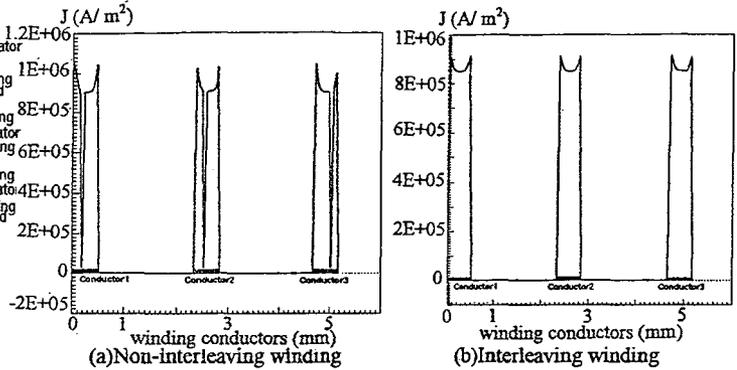


Fig.2 AC current distribution in winding conductors

3D simulation has an advantage in visualizing the field distribution in the third dimension. It's used here to estimate the leakage inductance arising from the extension of the winding layers outside the core. There are three different winding configuration to be studied here. Table 1 presents the calculated values for these three different structures. The magnetizing inductance L_m in structure 2 and 3 are almost the same because they have the same winding turns. However, structure 3 has a smaller leakage inductance L_k because of its interleaving winding arrangement. The ratio of the leakage inductance to the magnetizing inductance reflects the coupling efficiency of the transformer. It is 0.35 in structure 3, therefore it has a better coupling than structure 2. The leakage inductance structure 1 is much smaller than others because of its less winding turns. To obtain a small leakage inductance and a high coupling coefficient in a low-profile power transformer, it is therefore necessary to interleave the primary and secondary windings and minimize both the numbers of the primary and secondary winding turns.

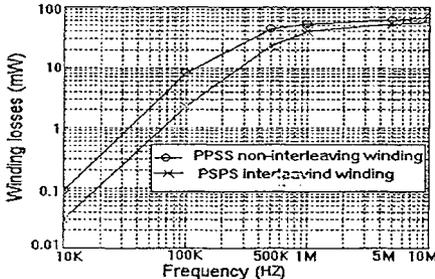


Fig.3 Winding losses vs frequency

Table 1 Winding leakage inductance at 500kHz

Structure	No1	No2	No3 interleaving
$L_m(\mu H)$	7.31	29.60	29.45
$L_k(nH)$	38.2	146.94	102.67
L_k/L_m	0.50	0.52	0.35

3. Conclusion

Skin and proximity effects cause additional winding losses to the transformer operating at high frequency. This losses become significant as frequency increases. Using interleaving winding effectively decreases the skin and proximity effects in winding conductors since it improves the uniformity of ac current distribution in the winding conductors. As a result, it reduces the winding ac resistance and hence lower winding losses. It also results in a smaller leakage inductance and good flux coupling. The planar-type transformer is therefore suitable for soft-switching converters such as the ZCS, ZVT-PWM [6].

Reference

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