Optimal Design of Resonance Frequency for LLC Converter

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Abstract

Recently, it is increased to use the portable device with small size. It is also increasing for demand of a small size adapter. To reduce the size of components, switching frequency has to be increased. But it causes higher switching loss and temperature of components. Especially, the temperature of adapter must be limited because adapter can be easily touched when portable device is being charged. To reduce temperature of adapter, high efficiency is essential. To solve this problem, this paper proposes design of resonance frequency optimization for LLC converter with high efficiency and low temperature of passive components.

1. Introduction

Now, potable devices such as smart phone, tablet pc are widely used. These mobile devices are required most likely to have a small volume and weight. Therefore, researches on high power density charger have been studied. To achieve this, passive components of inductors and capacitor which have large volume should be reduced.[1] High switching frequency may help to reduce the components. However, the higher operating frequency is, the higher magnetic components temperature is, because switching losses may be increased under the higher switching frequency. Especially, people often touch mobile device and adapter during charging battery. Therefore it is strictly necessary to regulate increasing adaptor temperature. To regulate the temperature of components, it should have high efficiency at high switching frequency. To achieve high efficiency, LLC resonant converter is normally adopted.[2]

In general, it takes a lot of time and effort to desing operating frequency for the LLC resonant converter. To solve this problem,,this paper presents the optimal design method of high switching frequency LLC converter with high efficiency and low temperature characteristics of the transformer. A prototype has been implemented to verify the validity of the proposed method.

2. Analysis of transformer loss

There are several parts of losses in the charger. First the loss of Diode, MOSFET and IC may be increased by increased switching frequency, but these components cannot affect increasing temperature of case because they have a small volume and enough distance from case to components.

However, in case of magnetic components such as transformer, which has large volume, it is difficult to have enough distance between case and components. If the temperature of transformer is increased, the temperature of case is affected directly. Therefore regulation of the transformer temperature is very important in mobile phone charger.

The transformer loss consists of core loss and wire loss. Calculation of the core loss is typically determined by the coefficients in table 1 which is provided by the core manufacturer, the core loss is shown in equation (1).[3]

$$P_{core} = a \cdot f_{sw}{}^{c} \cdot B_{\max}{}^{d} \cdot A_c \cdot l_c [mW] \quad (1)$$

Where B_{max} is peak flux density, f_{sw} is the operating frequency, Pcore is the total core loss , lc is the mean MPL and Ac is cross-sectional of the core.

Table 1. Empirical coefficients

Material	Frequency	a	c	d
R / Magnetics At 100℃	F<100 kHz 100 kHz≤f<500 kHz f≥500 kHz	0.074 0.036 0.014	1.43 1.64 1.84	2.85 2.68 2.2

In order to calculate the loss generated by the winding, rms current flowing through wire and resistance of wire are required. Since the skin depth is varied with operating frequency, the AC resistance of the wire should be considered. In general, the Litz wire is configured by considering the skin depth and eddy current loss . When Litz wire is applied, $Rw_{(Litz)}$ is shown by : [4]

$$R_{w(Litz)} = F_{R(Litz)} \cdot R_{wDC} = 1 + \frac{5 \cdot N_l{}^2 \cdot S - 1}{45} \cdot \left(\frac{\pi}{4}\right)^3 \cdot \eta_{\max}{}^2 \cdot \left(\frac{dl}{\delta_w}\right)^4 \cdot R_{wDC} \quad (2)$$

$$\delta_w = \sqrt{\frac{\rho_{cu}}{\pi \cdot u_o \cdot f_{sw}}},$$

$$R_{wDC} = MLT \cdot \frac{N_{pri}}{S} \cdot R_{20C^\circ} \cdot \left[1 + \frac{(R_{100C^\circ} - R_{20C^\circ}) \cdot (T - 20C\ )}{(100C\ - 20C\ ) \cdot R_{20C^\circ}}\right]$$

where N_l is the number of bundle layers, S is strand of litz wire, dl is wire diameter, η_{max} is maximum porosity factor. In the transformer, the rms current flowing through the resonant tank and the magnetizing inductance are given by:

$$L_m \le \frac{t_{dead} \cdot k}{16 \cdot C_j \cdot f_r} \quad (3)$$

$$I_{rms\_pri} = \frac{1}{8} \cdot \frac{V_{out}}{N \cdot R_L} \cdot \sqrt{\frac{2 \cdot N^4 \cdot R_L{}^2}{L_m{}^2 \cdot f_r{}^2} + 8\pi^2} \;;\quad I_{rms\_\sec} = \frac{\pi}{4} \cdot I_{out} \quad (4)$$

where magnetizing inductance is only considered ZVS condition for calculation convenience. The final value of magnetizing inductance should be also considered dc gain characteristics. k is empirical coefficients. If the number of turns is a lot and primary and secondary wire are separated, k is bigger than 0.8. If the number of turns is small and winding method is interleaved, k is smaller than 0.5. From equation (2) and (4), the winding loss of transformer is calculated by:

$$P_{wloss} = R_{w\_pri(Litz)} \cdot I_{rms\_pri}{}^2 + R_{w\_sec(Litz)} \cdot I_{rms\_sec}{}^2 \quad (5)$$

Table 2 shows specifications and design parameter for loss calculation.

Fig. 1 shows the core loss and winding loss according to operating frequency variation. The core loss is decreased by reduced flux density but copper loss is increased according to frequency increase due to higher Rac

Table 2. Specifications and design parameter

Vin	80 VDC	MPL	2.9 cm
Vout	12 VDC	MLT	3.1 cm
Pout	40 W	At	9.6 cm^2
Core (material) / Manufacture	RM6 (PC40) / TDK	Lp	47.85 uH (14T, 0.12 Ø ·25)
Turn ratio	3.5	Ls	4.04 uH (4T, 0.1Ø·40)
Ac	0.31 cm^2	Leq	2.02 uH

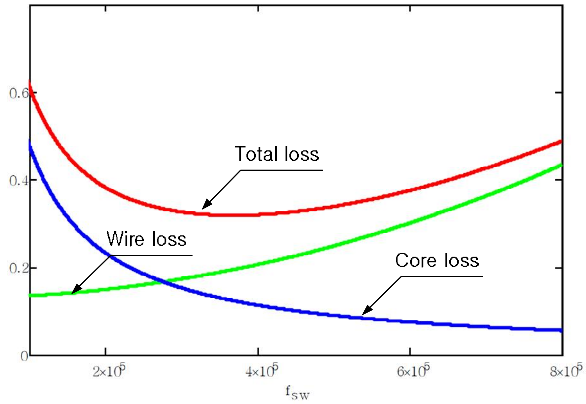

Fig. 1 Core loss and wire loss according to frequency variation

The temperature of transformer is determined by the core loss and winding loss as follow [5] :

$$T_{Trans} = 450 \cdot \left(\frac{P_{core} + P_{wloss}}{A_t} \right)^{0.826} + T_a \quad (6)$$

where, At is surface area of the transformer, Ta is ambient temperature.

3. Experiment result

The prototype of 40 W LLC resonant converter were implemented to verify the validity of the proposed design method having low-tempermature characteristics of the transformer. Specifications for test and transformer are the same with those in table 2. Fig. 2 shows transformer temperature according to operating frequency variation in both the experimental results and calculated result. Not only experimental results but also calculated result showed that the temperature was decreased from 200 kHz to 400 kHz and then increased to 800 kHz.

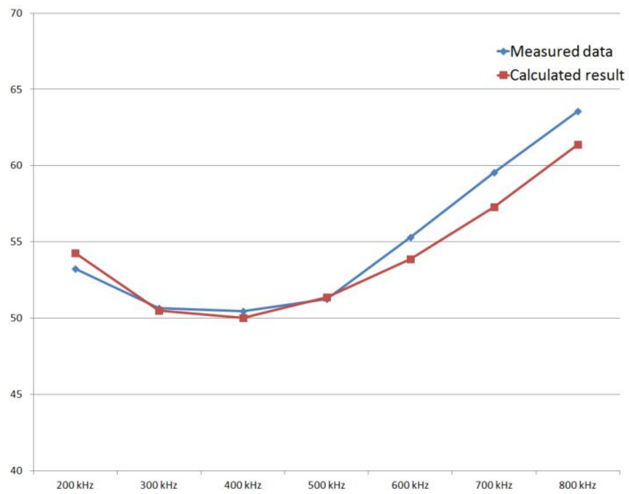

Fig. 2 Transformer temperature according to operation frequency variation

4. Conclusion

This paper proposed the optimal design method of high switching frequency LLC converter with high efficiency and low temperature characteristics of the transformer. The core loss and winding loss are analyzed and theoretical temperature of transformer is calculated. In the experiment, optimal operating frequency is verified and this results well matched with theoretical analysis. Therefore, the proposed design method can provide high power density and small size design of portable device chargers.

Reference

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