A Transformer with Adjustable Leakage Inductance

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Abstract—The leakage inductance of the transformer employed in a series resonant converter can be used for resonance to make the device more compact. The value of this inductance should be controllable and sufficient large. In this paper the novel structure of a transformer with adjustable leakage inductance is proposed and the design methodology is presented so as to reduce the size of power resonant converters.

I. Introduction To The Transformer

The configuration of the proposed transformer is shown in Fig. 1. Two U cores are used to construct an enclosed magnetic path without any air-gap. The windings W_P and W_S, wound around the left legs, are, respectively considered as the primary and secondary windings of a typical transformer. As there is no air-gap between the two U cores, the leakage inductance is very small and it is difficult to estimate its value. To increase the leakage inductance, another small U core is attached to the right side leg of the core with an appropriate air-gap to provide a path for the leakage flux as shown in Fig. 1. The winding W_1 wound on the right leg is in series with W_P. Some of the flux through winding W_1 would follow the path provided by the small U core and therefore these are considered as leakage component. The level of leakage can be adjusted by regulating either the length of the air-gap or the number of turns of W_1. Not high level of leakage inductance is required while used in resonant converters due to high switching frequency. Hence W_1 does not have not many turns. The AC voltage is applied between terminals 1 and 4. W_1 acts like a leakage inductor in series with a mutual inductor with respect to the primary winding W_P.

II. Modeling

The magnetic reluctance model of the integrated magnetic device is shown in Fig. 2. The equivalent reluctances of the core in the left and the right leg are denoted as R_2 and R_1, respectively. The reluctance of the magnetic path for the leakage flux is denoted as R_0. The symbols n_1, n_p and n_s are the number of turns of the windings W_1, W_P and W_S, respectively. According to duality principle, the associated electrical circuit model is shown in Fig. 3, where the inductances L_0, L_1 and L_2 referred to winding W_1 are expressed as,

$$L_0 = \frac{n_1^2}{R_0}, \quad L_1 = \frac{n_1^2}{R_1}, \quad L_2 = \frac{n_1^2}{R_2}.$$

III. Calculation & Results

Equations (1) to (4) can be derived from Fig. 3 using basic circuit laws. The relationship among the input voltage, input current and output voltage is deduced from above equations as shown in (5). Therefore the equivalent leakage inductance L_k is acquired as shown in (6). It can be seen that L_k is related to L_0 whose value can be adjusted by regulating either the length of the air-gap or n_1, which is the turn number of the winding W_1. The equivalent number of turns of the primary winding of the transformer is n_a, which is expressed by (7).

$$L_1 \frac{di_1}{dt} + \frac{n_p}{n_1} v_1 = v_{in} \tag{1}$$

$$L_0 \frac{di_0}{dt} + v_1 = L_1 \frac{di_1}{dt} \tag{2}$$

$$v_1 = \frac{n_1}{n_s} v_s \tag{3}$$

$$i_0 + i_1 = i_{in} \tag{4}$$

$$v_{in} = \frac{L_1 \cdot L_0}{L_1 + L_0} \frac{di_{in}}{dt} + \frac{n_p + n_1 \cdot \frac{L_1}{L_1 + L_0}}{n_s} \cdot v_s \tag{5}$$

$$L_k = \frac{L_1 \cdot L_0}{L_1 + L_0}. \tag{6}$$

$$n_a = n_p + n_1 \cdot \frac{L_1}{L_1 + L_0} \tag{7}$$

A magnetic device has been developed. The parameters of the magnetic structure are tabulated in table I. Fig. 4 shows the curves of leakage inductance against n_1. These curves are achieved through calculation, FEM analysis and experiment, respectively. Good agreement is obtained.

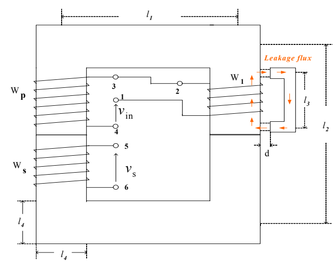

Fig. 1. The structure of the transformer.

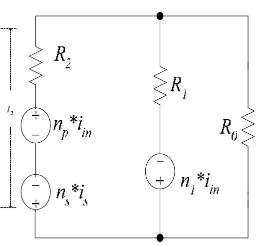

Fig. 2. The reluctance model.

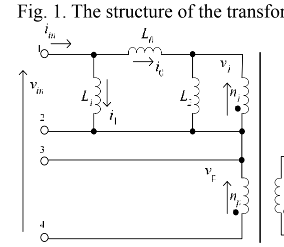

Fig. 3. The electrical circuit model.

TABLE I
STRUCTURE PARAMETERS

l_1	4.5 cm
l_2	6.8 cm
l_3	2.4 cm
l_4	1.6 cm
depth	2.2 cm
δ	0.2 cm

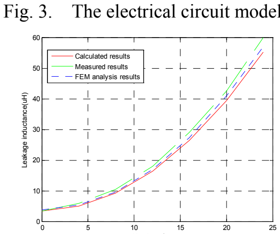

Fig. 4. Leakage inductance against n.

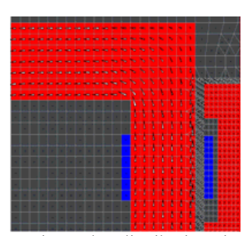

Fig.5. Flux distribution via FEM.

IV. References

[1] J. K. Watson, Applications of Magnetism, 1985, pp. 273-278.

Acknowledgment

Supported from ITF project 073/04 are appreciated