

Fast Calculation Approach of Parameters in High Frequency Transformer Model Derived from Magnetic Circuit

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The increasing power electronic converters in the power system bring high frequency harmonics, which affect the normal operation of power transformers. The transformer circuit model derived from magnetic circuit conversion has been proved to have good accuracy in transient simulation of power systems, but it cannot reflect the impact of high frequency harmonics on transformers. This paper establishes a high frequency nonlinear transformer topology and proposes a method for quickly calculating model parameters. Parameter inversion can be achieved solely by using the parameters on the nameplate. The magnetic flux is used to invert nonlinear inductance, and the electromagnetic relationship of the transformer is used to invert parasitic capacitance. The proposed fast calculation model is very suitable for power system simulation, as it can effectively reflect the impact of high frequency harmonics on power equipment.

Index Terms—High frequency transformers, inductance, magnetic circuits, parasitic capacitance.

I. INTRODUCTION

THE HIGH frequency of power electronic equipment brings many high frequency harmonics to the power grid. By constructing a high frequency transformer model, the operation state of the circuit at high frequency can be accurately reflected.

The traditional high frequency transformer mainly adds capacitance to the power frequency T-type transformer [1]. This method is simple and intuitive, but the T-type transformer cannot accurately reflect the magnetic circuit. The excitation inductance is generally expressed by linear inductance, without considering the saturation state of the transformer. Parasitic capacitance is generally calculated by obtaining electric field energy through finite element method [2], which requires large calculation resources and takes a long time.

In this paper, a high frequency transformer model is constructed by calculating the nonlinear excitation inductance and applying it to the unified magnetic circuit (UMEC). In order to improve the parameter calculation efficiency of the model, the capacitance fitting expression related to capacity and voltage is obtained according to the transformer structure.

II. ESTABLISHMENT OF HIGH FREQUENCY UMEC MODEL

UMEC is a method to obtain the Norton equivalent circuit from the magnetic circuit, which accurately reflects the magnetic field distribution in the transformer core. The magnetic circuit topology of single-phase transformer is shown in Fig. 1: R_i ($i=1\sim5$) is reluctance, MMF_j ($j=1,2$) is the magnetomotive force that is reasonably placed on the magnetic circuit.

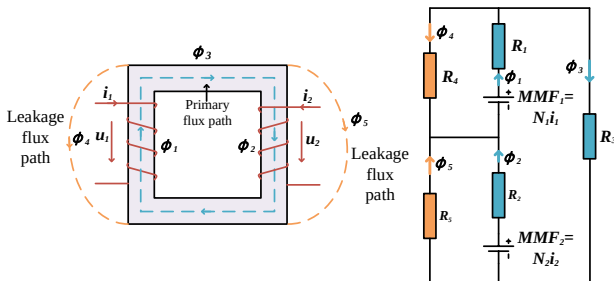


Fig. 1. Single phase double winding magnetic circuit topology.

The relationship between magnetic flux ϕ , current and MMF is expressed by Nodal magnetomotive force equation

$$\phi = [P^*]([N]i - M'), \quad (1)$$

where P^* is the permeance, $[N]i$ is the magnetomotive force from the winding, M' is the branch magnetomotive force. Through transformation, the relationship between magnetic flux ϕ and current can be expressed as

$$\phi = [Q^*][P^*][N]i, \quad (2)$$

where Q^* is the matrix related to permeance. Magnetic flux is the integral form of voltage, so the Norton equivalent circuit expression of UMEC is

$$i_s(t) = [Y_{ss}^*]v_s(t) + i_{ns}^*(t), \quad (3)$$

where Y_{ss}^* is the admittance matrix, i_{ns}^* is the current source.

The nonlinear relationship between excitation current i and flux linkage is ψ at the terminal of the winding is fitted as

$$i = \frac{\sqrt{(\psi - \psi_k)^2 + \beta^2 - \psi_k^2} + \psi - \psi_k}{2L_{air}} + \frac{\psi_k - \beta}{2L_{air}}. \quad (4)$$

where ψ_k is the parameter that determines the offset of the fitted curve on the ψ axis, L_{air} is hollow core inductance, β is a constant related to flux and current. The nonlinear excitation inductance at the terminal can be calculated by the current obtained from (4). Then, nonlinear permeance P^* is obtained according to the duality principle. This means that the admittance in the circuit model can be determined. Furthermore, by adding parasitic capacitance to the circuit model, a typical three capacitor high-frequency model is formed, as shown in Fig. 2. Y_{11} and Y_{22} are the self admittances, Y_{12} is the mutual admittance, i_{ns1} and i_{ns2} represent the current sources, C_1 is the capacitance of the primary winding to the ground, C_2 is the

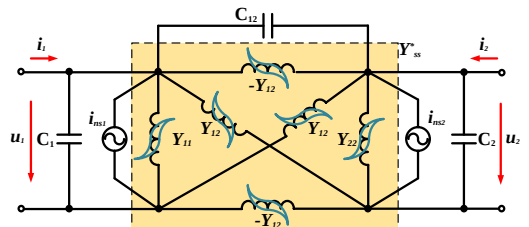


Fig. 2. High frequency UMEC equivalent circuit.

capacitance of the secondary winding to the ground, and C_{12} is the capacitance between the primary and secondary windings.

III. FAST CALCULATION METHOD OF PARASITIC CAPACITANCE

The calculation of the general capacitance is considered that the winding voltage is a constant value, and the static capacitance is obtained according to the electric field energy. The parasitic capacitance considers the distribution of voltage on the winding. The total electric field energy obtained by calculus is equivalent to the energy expressed by the lumped dynamic capacitance. The capacitances are given as

$$\begin{cases} C_1 = \frac{\varepsilon_0 \varepsilon p_1 h_1}{3\Delta_1} \\ C_2 = \frac{\varepsilon_0 \varepsilon p_2 h_2 n^2}{\Delta_2 m^2} \\ C_{12} = \frac{\varepsilon_0 \varepsilon S_{12}}{3\Delta_{12}} \left(\frac{n}{m} + 1\right)^2 \end{cases}, \quad (5)$$

where, ε is the relative dielectric constant, p_i ($i=1,2$) is the average turn length of the winding coil, Δ_i ($i=1,2$) is the gap between magnetic core and winding, Δ_{12} is the gap between the primary and secondary windings, h_i ($i=1,2$) is the height of the winding.

The solution of capacitance can be realized in the structural design of transformer. By setting the structural parameters and iterative conditions of the transformer, the data such as turn length and gap under the specified parameters can be solved to obtain the capacitance. The nonlinear fitting of capacitance under different capacity and voltage is carried out, and the fitting curves of C_1 and C_{12} are shown in Fig. 3. It can be observed that the capacitance and voltage have an obvious nonlinear relationship.

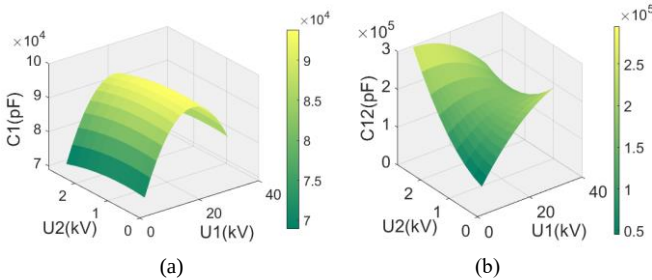


Fig. 3. Capacitance fitting surface diagram: (a) primary side to ground capacitance. (b) primary side to secondary side winding capacitance.

IV. SIMULATION AND ANALYSIS

This paper takes single-phase double winding transformer (3MVA, 36.75kV/0.69kV) as the research object, and uses C++ to program the high frequency UMEC model.

Fig. 4 shows the primary side current of the UMEC model before and after increasing capacitances in the low frequency state. Due to the nonlinearity of excitation inductance, the primary current has obvious inrush current. Compared with the current waveform, the addition of capacitance has little effect on the current at low frequency, which is in line with the characteristics that the parasitic capacitance can be ignored at low frequency.

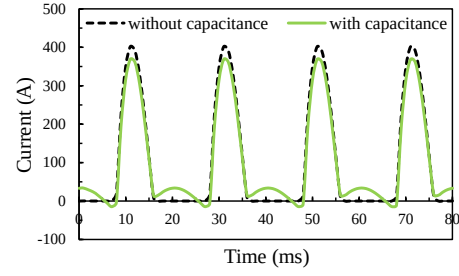


Fig. 4. Waveform before and after adding capacitance to primary current at 50Hz.

In order to fully analyze the current of the high frequency model, the primary current at 1kHz, 1.5kHz and 2kHz is compared, as shown in Fig. 5. At high frequency, the inrush current waveform has harmonic oscillation, and the amplitude is positively correlated with the frequency. The above results show that the capacitance cannot be ignored at high frequency, and its characteristics affect the inrush current of the excitation inductance. If the change of magnetization characteristic at high frequency is further considered, the influence of current will be more obvious.

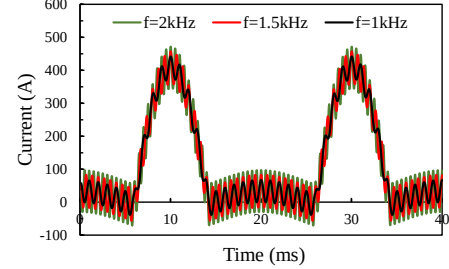


Fig. 5. Primary current of high frequency UMEC model.

V. CONCLUSION

In order to solve the problem that the current high frequency transformer model does not fully consider the magnetic circuit characteristics, saturation characteristics, and complex parameter calculation. This paper obtains a high frequency nonlinear equivalent circuit based on mature magnetic circuit conversion, and proposes a method for quickly determining parasitic capacitance based on rated nameplate parameters. The simulation results show that the capacitance cannot be ignored at high frequency, and its characteristics affect the inrush current of the excitation inductance.

VI. ACKNOWLEDGMENT

This work was supported by "the National Natural Science Foundation of China" (52304275) and "the Fundamental Research Funds for the Central Universities (2024ZKPYJD07).

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