A NEW IDENTIFICATION METHOD OF BOTH MAGNETIZATION CHARACTERISTIC AND PARAMETERS OF AN UNLOADED TRANSFORMER

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Summary In this paper a new method of identification of both the magnetization characteristic and the instantaneous parameters $G(t)$ and $K(t)$ of a single-phase transformer under a sinusoidal supply voltage is proposed. The instantaneous conductance $G(t)$ and inverse inductance $K(t)$ of the transformer cross section are determined by the scalar product of time functions. The magnetization characteristic is derived by means of the inverse inductance $K(t)$. The method is practically applied to an isolating transformer.

1. INTRODUCTION

The transformer is a key device for electrical energy transfer. For simulation of its behavior in electrical practice we have to know transformer parameters and characteristics. Different models of transformers have been researched for long time e.g. in a time domain [1]. A new way of both parameters identification and magnetization characteristic of the model cross section of an unloaded single-phase transformer from a time record of both the voltage waveform $u(t)$ and the current waveform $i(t)$ by scalar product of time functions [2] is presented below.

2. THEORY

The cross section model of an unloaded transformer is created in Fig. 1 by parallel combination of both the conductance G and the inverse inductance K. These circuit parameters are not constant. In fact they are changed in time because the transformer is a non-linear device, as well-known.

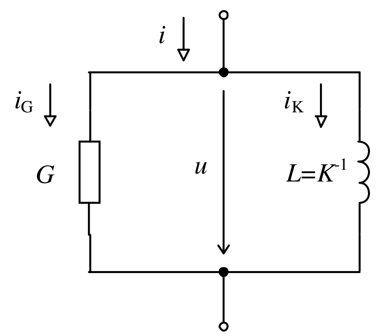

Fig. 1. The linear model of the transformer cross section

Identification of the instantaneous parameters $G(t)$ and $K(t)$ is generally difficult. Using so-called "The Circuit Integral Transformation" for two elements model [3] a constant values of these parameters can be determined by scalar product defined over a small time interval (t_a, t_b) with the length $\Delta t = t_b - t_a$

$$\begin{bmatrix} G \\ K \end{bmatrix} = \begin{bmatrix} (u,u) & (u^x,u) \\ (u,u^x) & (u^x,u^x) \end{bmatrix} \cdot \begin{bmatrix} (i,u) \\ (i,u^x) \end{bmatrix}, \qquad (1)$$

where the symbol (,) denotes the function of the scalar product and u^x is an integral of the voltage $u(t)$ over time t.

If the voltage and current signals will be regularly sampled at the sample rate f_s we get sequences of sampled values of the ones at the discrete time instant t_i i.e. $u(t_i)$ and $i(t_i)$ instead of the instantaneous values $u(t)$ and $i(t)$. Let us suppose that a time period T of the voltage and current waveforms is an even integer multiplicand N of the time interval $t_s = f_s^{-1}$ between consecutive samples, then $T = N.\ t_s$.

The period T can be splitted into even N_k ($N_k << N$) number of the consecutive time intervals Δt in which the parameter $G_k(t_i) = G$ and $K_k(t_i) = K$, determined by (1), are constant values. The sequences of the cross section current values of the transformer can be obtained from following equations

$$\begin{aligned} i_G(t_i) &= G_k(t_i) \cdot u(t_i) \\ i_K(t_i) &= K_k(t_i) \cdot u^x(t_i) = K_k(t_i) \cdot \Psi(t_i), \end{aligned} \qquad (3)$$

where Ψ is the magnetic flux.

3. EXPERIMENTAL

Utilizing this method will be demonstrated by a measurement on the isolating transformer TVO120 with ratings of 220V/220V, 2500VA, 11,4A. The primary winding resistance of the transformer has been 180 mΩ, so that is negligible. The transformer was fed by the AC power source Kikusui PCR 1000LA, operated in sinusoidal mode at the voltage about 250 V and the frequency 50 Hz i.e. at the angular frequency $\omega = 100.\pi$. The voltage and current signals were acquired by DAQ card PCI MIO 16-E1 at the sample rate 50 kSa/s and are showed in Fig. 2.

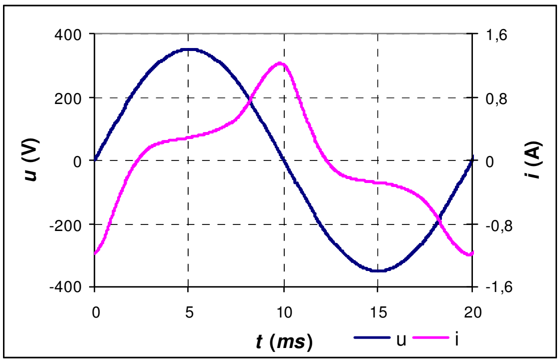

Fig. 2. The measured voltage and current waveform, U = 248,7 V, I = 0,62 A

The computed values of the parameters $G_k(t_i)$ and $K_k(t_i)$ in the consecutive time intervals $\Delta t = 200\ \mu s$ are visualized in Fig. 3 and Fig. 4, respectively. For the purpose of the transformer

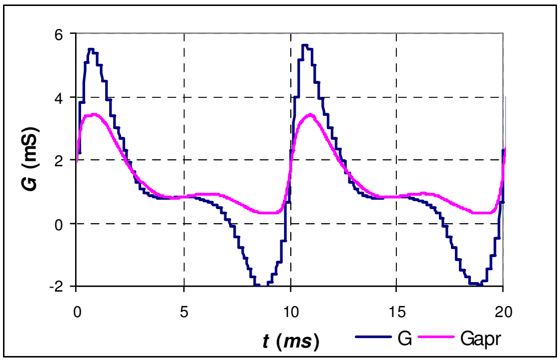

Fig. 3.The instantaneous conductance $G_k(t_i)$

cross section modeling the waveform $K_k(t_i)$ can be approximated by a few terms of the Fourier series, in our case simply by three terms

$$K_{apr}(t) = a^2 K_0 + a\, K_2 \cos(2\omega t) + a\, K_2 \cos(4\omega t) =$$
$$= 0{,}512 + 0{,}523 \cos(200\pi\, t) + 0{,}039 \cos(400\pi\, t)$$

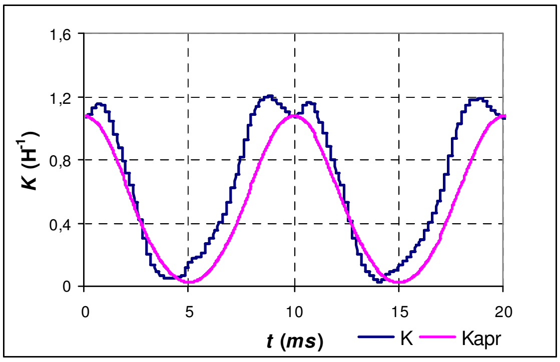

Fig. 4 The instantaneous inverse inductance $K_k(t_i)$

where $K_0 = 0{,}647\ H^{-1}$, $K_2 = 0{,}593\ H^{-1}$, $K_4 = 0{,}044\ H^{-1}$ are the Fourier coefficients of $K_k(t_i)$ and $a = 0{,}89$ is the modify scale because the values of $K_k(t_i)$ (but also the ones of $G_k(t_i)$) are only linearized in the interval Δt. The value a can be determined by extremes of the waveform $K_k(t_i)$

$$a = \frac{\max_{lok} - \min}{\max - \min} = \frac{1{,}075 - 0{,}027}{1{,}204 - 0{,}027} \doteq 0{,}89 \,. \qquad (5)$$

The approximated waveform of $K_{apr}(t)$ is then shown in Fig. 4 for the comparison.

The voltage waveform in Fig. 2 is given

$$u(t) = U_m \sin(\omega t) = 351{,}7 \sin(100\pi\, t) \qquad (6)$$

the corresponding magnetic flux is

$$\Psi(t) = \frac{U_m}{\omega} \cos(\omega t) = \Psi_m \cos(\omega t) = \qquad (7)$$
$$= 1{,}12 \cos(100\pi\, t)$$

and for the approximated magnetizing current it follows that

$$i_{Kapr}(t) = K_{apr}(t) \cdot \Psi(t) = \Psi_m [a(a\, K_0 - K_2 + K_4) \cdot$$
$$\cdot \cos(\omega t) + 2a(K_2 - 4K_4) \cos^3(\omega t) + 8aK_4 \cdot$$
$$\cdot \cos^5(\omega t)] = 0{,}027 \cos(100\pi\, t) + 0{,}831 \cos^3(100\pi\, t) +$$
$$+ 0{,}35 \cos^5(100\pi\, t) \qquad (8)$$

Substituting (7) into (8) the time t is eliminated and the approximated magnetizing characteristic in Fig. 5 is then defined

$$i_{Kapr} = a(aK_0 - K_2 + K_4)\Psi + \frac{2a(K_2 - 4K_4)}{\Psi_m^2} \Psi^3 +$$
$$+ \frac{8aK_4}{\Psi_m^4} \Psi^5 = 0{,}024\, \Psi + 0{,}593\, \Psi^3 + 0{,}2\, \Psi^5 \qquad (9)$$

in the form that is useful for numeric simulation of the transient phenomenon of the transformer with reasonably good accuracy.

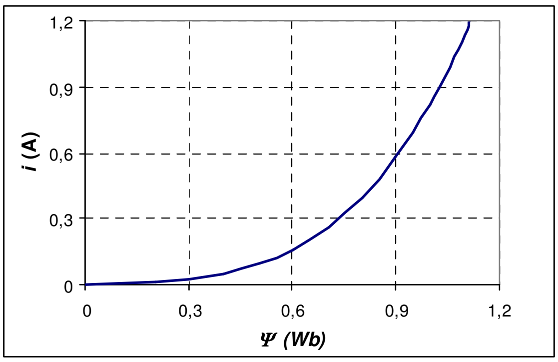

Fig. 5. The magnetization characteristic

The approximated current, respecting the eddy current and hysteresis core losses, can be determined by applying the first Kirchhoff's law

$$i_{Gapr}(t) = i(t) - i_{Kapr}(t) \tag{10}$$

and the corresponding conductance waveform

$$G_{apr}(t) = \frac{i_{Gapr}(t)}{u(t)} . \tag{11}$$

To avoid singularities in (11) the values of conductance $G_{apr}(t_i)$ instead of $G_{apr}(t)$ can be computed by the scalar product of both the voltage waveform $u(t_i)$ a the current waveform $i_{Gpr}(t_i)$ in the consecutive time intervals Δt of the number N_k as above. The approximated non-negative waveform of $G_{apr}(t_i)$ by the Fourier series is then shown in Fig. 3.

The both approximated waveform currents $i_{Gpr}(t_i)$ and $i_{kpr}(t_i)$ are visualized in Fig. 6.

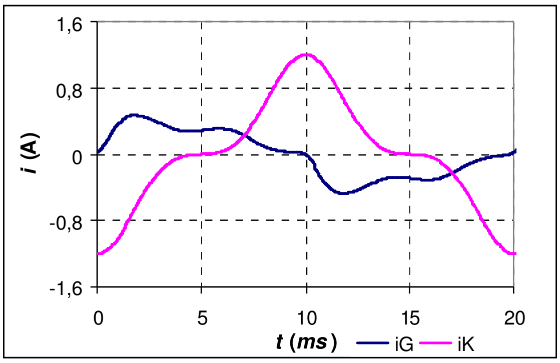

Fig. 6. The current waveform $i_{Gpr}(t_i)$ and $i_{Kapr}(t_i)$

4. CONCLUSION

The proposed determination method of both the magnetization characteristic and the magnetization current of the transformer is derived from the waveform $K(t)$. Identification of the instantaneous values of the inverse inductance $K(t)$ is much simpler then the one of the inductance $L(t)$ in [1] because the time waveform $K(t)$ contrary of the $L(t)$ can be easy approximated by a few terms of the Fourier series. The number of terms (9) is sufficient for simulation of the transient phenomenon of the transformer. We will try to modify this method so that the time waveform $G(t)$ would be also symmetrical.

Acknowledgement

This work has been supported by research program "IGA" of the Faculty of Electrical Engineering and Computer Science of the VSB - Technical University in Ostrava.

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