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Calculation Of High Harmonics Produced By The Saturation Of A Magnetic Core Of A Current Transformer

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ABSTRACT

The article developed an expression that allows to determine the amplitude values of different harmonics of the magnetizing current at high harmonics caused by the saturation of the magnetic core of the current transformer. Using this expression, it is possible to determine the percentage of the main harmonics obtained for different harmonics, and the determined results allow to accurately set the value of the current (voltage) in the transition state from one range to another to automatically adjust the range of the current transformer.

KEYWORDS

Auto-adjustable current transformer, magnetizing current, high harmonics, magnetic coil, linear-segment approximation.

INTRODUCTION

The occurrence of high harmonics in the power grid can be realized not only by consumers with nonlinear volt-ampere characteristics [1], but also under certain conditions directly by network equipment, i.e. current transformers [2]. The main reason for this is that the weber-ampere characteristic of the transformer magnet coil is actually nonlinear. However, at rated voltage, the value of the operating current, determined by the main harmonics of the magnetizing current, in most cases does not exceed 1% of the rated current [3]. Therefore, this value does not significantly affect the overall harmonic background of the power grid, as the value of the maximum allowable voltage increases (by 20%) and the magnetization current increases by a

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maximum of 2-5 times, although the odd harmonics appear. [4].

The high harmonics generated by the saturation of the magnetic core of a high-voltage power transformer have been studied by the world's leading scientists. However, little attention has been paid to scientific research aimed at calculating the high harmonics generated by the saturation of the magnetic core of a current transformer. Therefore, this article focuses on the development of a sequence of calculations of high harmonics generated from the saturation of the core of a current transformer.

THE MAIN FINDINGS AND RESULTS

In order to take into account the flattening effect of the magnetizing current of the current transformer, we are satisfied with a single breaking point $\Psi = f(t)$ in the linear-fractional approximation of the magnetization characteristic. In the linear-fractional approximation of the magnetization characteristic, the calculated level of harmonics is slightly higher than the experimental values [9], which allows to obtain a boundary value.

Figure 1 shows the magnetization characteristic of a current transformer «$\Psi(t)$ flow – i_μ linear-fractional approximation to the coordinates "magnetization current", which is a characteristic $(\Psi_S,\ I_S)$ given by the unsaturated and $(L_\mu,\ i_\mu < I_S\ )$ saturated values of one breaking point and two magnetization inductors $(L_{\mu(S)},\ i_\mu > I_S$ б) given with saturated values.

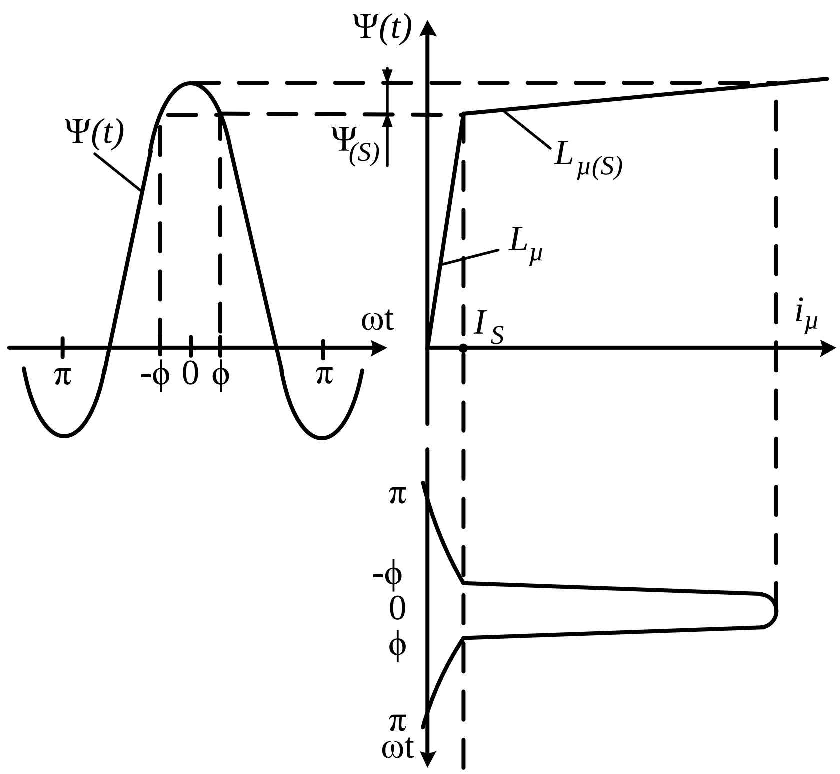

Figure 1. linear-fractional approximation of the magnetization characteristic of a current transformer

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The instantaneous value curve of the current $\Psi(t)$ in a high-voltage (HV) coil explains the process of generating a unipolar magnetizing current.

In general, in linear-segment approximation, the breakpoint coordinates $I_S = k_I \cdot I_x$ and $\Psi_\text{S} = k_\psi \cdot \Psi_\text{m}$ should be selected taking into account the salt operating current I_S in the passport of the transformer and the amplitude values Ψ_m of the winding current HV at rated voltage. Proportionality coefficients k_I, k_ψ allow to take into account the real state of the magnetic line of current transformers in the mode of nominal or voltage deviation from the nominal (k_ψ = 0,8÷1,2) depending on the design value of the working induction. By selecting the coefficient of proportionality, it is possible to shift the position of the breaking point in the linear-fractional approximation of the magnetization curve, taking into account the individual design features of the transformer and the operating mode. The values of the proportionality coefficients are assumed to be k_ψ =1,0 and k_I= 1,0 without affecting the generality of the results obtained for further analysis.

In this case, the unsaturated value of the magnetic inductance in the linear-fractional approximation is determined by the following expression

$$L_\mu = \frac{\mu\mu_0 w_2^2 S k_a}{l} \qquad (1)$$
$$k_a = \frac{S_a}{S_\text{г}}$$

where l –is average length of the magnetic path, м;μ – relative magnetic permeability; μ_0– magnetic constant, Гн/м; w – the number of windings of the primary winding, the number of windings of the secondary winding of the current transformer $w_2 = 200$; S– magnetic core cross-sectional area, м²; S_a– magnetic core active cross-sectional surface, м²; $S_\text{г}$– magnetic core geometric cross-sectional area, м². We assume that the total surface area of the magnetic core cross section is useful $k_a = 1$.

The inductive resistance of a magnetizing coil in the field of technical saturation consists of two components:

$$x_{\mu(S)} = x_{\mu(S)}^{(\text{э})} + x_{HV},$$

one of them ($x_{\mu(S)}^{(\text{э})} = k\omega L_{\mu(S)}$) the main magnetic flux flowing from the magnetic conductor in the state of technical saturation and the second (x_{HV}) эса HV is the scattering current of the coil. The value of the scattering current of the load winding can be approximated by the value of the inductive component of the short-circuit resistance ($x_{HV} \approx 0{,}5x_\text{T}$) given in the transformer passport. The value of the second component may not be taken into account when calculating the inductive resistance of the magnetizing coil in the field of technical saturation, taking into account the operating mode of the current transformer.

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The rate of change of magnetism inductance during the transition from the working magnetization field to the technical magnetization field is characterized by the following relationship:

$$K_\mu = \frac{L_\mu}{L_{\mu(S)}^{(э)}} \approx \frac{\mu_d}{\mu_{d(S)}}\,, \qquad (2)$$

Where is μ_d, $\mu_{d(S)}$ – the relative differential magnetic susceptibility of the electrotechnical steel magnetic conductor in the field of pre-saturation and technical saturation, respectively (E-310 electrotechnical steel main magnetization curve is $K_\mu = 142{,}86$ in the linear-fractional approximation [4].

Based on the relations (1) - (3), the inductive resistance of the transformer magnetizing coil in the field of technical saturation, the parameters of the technical saturation of electrotechnical steel (K_μ) and the design properties of the magnetic system and HV coils are determined by
K_x:

$$x_{\mu(S)} = \frac{\omega L_\mu}{K_\mu} = \frac{x_\mu}{K_\mu} \qquad (4)$$

The following conditions are taken into account when determining the magnetic current for the current transformer under study:

- The phase voltage of the mains at the junction of the current transformer forms a symmetrical system and maintains its sinusoidality even under active geomagnetic conditions.;
- The instantaneous value of the current coupling of the phase coil with HV differs from each other only in the presence of phase shift in the active geomagnetic conditions and in its absence.

To determine the instantaneous values of the magnetizing current under the given conditions, it is sufficient to consider the super-magnetization mode in only one phase of the power transformer.

For harmonic components in the instantaneous values of the current coupling value generated by a sinusoidal voltage, the following expression is appropriate:

$$\Psi(t) = \Psi_m cos\omega t \qquad (5)$$

Where is $\Psi_\mathrm{m} = \frac{U_m}{k\omega}$ – amplitude value of current coupling; $U_{\text{ном}}$— the nominal linear voltage across the power transformer HV.

The instantaneous values of the magnetizing current in the field of working super-magnetization $|\Psi(t)| \leq \Psi_S$ are determined as follows, taking into account the expression (5)

$$i_\mu(t) = \frac{\Psi_m cos\omega t}{L_\mu} \qquad (6)$$

The magnetization current corresponding to the breaking point in the linear-segmental

approximation of the magnetization characteristic is determined as follows:

$$I_S = \frac{\Psi_m cos\varphi}{L_\mu} \qquad (7)$$

Where is φ – is the phase angle of saturation of the magnetic system, which determines the moment when the current saturation saturation is equal to the value Ψ_S.

Technical saturation of the magnetization characteristics$|\Psi(t)| > \Psi_S$ The magnetization current in the field can be determined by the following relationship:

$$\frac{\Psi(t) - \Psi_S}{i_\mu(t) - I_S} = L_{\mu(S)}. \qquad (8)$$

The value of the current coupling corresponding to the breaking point of the

linear-fractional approximation of the magnetization characteristic Ψ_S is determined as follows:

$$\Psi_S = \Psi_m cos\varphi. \qquad (9)$$

Thus, taking into account (6), (7) and (8), we have the following system of equations to determine the instantaneous values of the magnetization current:

$$\begin{cases} \\ \\ \end{cases}$$

$$i_\mu(t) = U_m cos\varphi\left(\frac{1}{x_\mu} - \frac{1}{x_{\mu(S)}}\right) + \frac{U_m}{x_{\mu(S)}} cos\omega t \quad (10)$$

Where is $|\Psi| > \Psi_S$;

$$i_\mu(t) = \frac{U_m cos\omega t}{x_\mu} \quad (11)$$

Where is $|\Psi| \leq \Psi_S$.

To determine the instantaneous values of the magnetizing current using the expressions (10) and (11) in the system of
equations, we create the following expression:

$$i_\mu(t) = U_m\left(\frac{1}{x_\mu} - \frac{1}{x_{\mu(S)}}\right)(cos\varphi - cos\omega t). \quad (12)$$

Using expression (4), expression (12) can be written as follows:

$$i_\mu(t) = \frac{U_m}{\omega L_\mu}(1 - K_\mu)(cos\varphi - cos\omega t) \quad (13)$$

This expression is the result of the effect of correcting the magnetization current curve based on the nonlinearity of the magnetization characteristic. In the linear characteristic of magnetization ($x_\mu = x_{\mu(S)}$) there is no correction effect.

The periodic curve shown in Figure 1 is a symmetric function of the pair and the ordinate axis. When this function is propagated to the Fure series, it has no sine constituents, only cosine constituents whose constant and initial phase is zero, i.e.:

$$i_\mu(t) = I_0 + \sum_{k=1}^{\infty} I_{\mu(k)} cosk\omega t, \quad (14)$$

$$I_0 = \frac{1}{2\pi}\int_0^{\varphi} i_\mu(t)dt, \quad (15)$$

$$I_{\mu(k)} = \frac{1}{\pi}\int_{-\varphi}^{\varphi} i_\mu(t) cosk\omega t dt, \quad (16)$$

where I_0 – is a constant component of the magnetizing current; $I_{\mu(k)}$ – is the amplitude value of the k-harmonics of the magnetization current.

Using the expressions (13) and (15), it is possible to determine the value of the constant component of the magnetization current:

$$I_0 = \frac{U_m}{\pi\omega L_\mu}(1 - K_\mu)(\varphi cos\varphi - sin\varphi). \quad (17)$$

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Using the expressions (13) and (16) it is possible to determine the amplitude value of the k-harmonic magnetization current:

$$I_{\mu(k)} = \frac{2U_m}{\pi\omega L_\mu}(K_\mu - 1)\left(\frac{1}{2}\left(\frac{\sin(\varphi(k+1))}{k+1} + \frac{\sin(\varphi(k-1))}{k-1}\right) - \frac{\cos(\varphi)\sin(k\varphi)}{k}\right), \quad (18)$$

Using the developed expression (18), it is possible to determine the magnetization current even and odd harmonics. Also, in the linear characteristic of magnetization ($x_\mu = x_{\mu(S)}$) the high harmonics of the magnetizing current are equal to zero, i.e.$I_{\mu(k)} = 0$. The high harmonics of the magnetizing current are zero even when $\varphi = 0$ or $\varphi = \pi$.

(18) the expression represents the basic harmonics of the magnetizing current when $k = 1$:

$$I_{\mu(1)} = \frac{U_m}{\pi\omega L_\mu}(K_\mu - 1)\left(\varphi - \frac{\sin 2\varphi}{2}\right), \quad (19)$$

(18) the expression represents the third harmonic of the magnetizing current when $k = 3$:

$$I_{\mu(3)} = \frac{U_m}{18\pi\omega L_\mu}(K_\mu - 1)(3\sin(2\varphi)(\cos 2\varphi + 1) - 4\cos\varphi\sin 3\varphi), \quad (20)$$

CONCLUSION

Thus, the range under study allows to determine the amplitude values of the various harmonics of the expression magnetization current, designed to determine the saturation current of the magnetic core of an automatic adjustable current transformer. This expression also determines the percentage of the main harmonics obtained for different harmonics, which in turn allows to accurately set the value of the current (voltage) in the transition state from one range to another to automatically adjust the range of the current transformer under study.

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