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Calculation Of The Transient Process When Switching On Power Transformers

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Abstract — *This article analyzes the transition processes that occur during the switching on of power transformers.*

Keywords — the transformer, accumulation, magnetization, magnetic circuit.

Introduction

When the operating mode of the transformer changes, a transition occurs from one steady state to another. Usually this process lasts a short time, but it can be accompanied by very dangerous phenomena for the transformer. The reliability of a transformer is determined not only by its operation in steady-state modes, but also in transient ones, for example, when it is turned on. When the transformer is connected to the network, current surges, called turn-on currents, exceeding the nominal current in steady-state mode, can be observed, although the no-load current does not exceed 3-5% of the nominal [1]. Such switching current surges cause complications in the design and adjustment of the protective current relays of transformers, since they can cause false operations of these relays when the transformer is turned on at idle speed. During start-up of the transformer, overcurrents flow through its primary winding, which adversely affect the insulating properties of the winding caused by sharp mechanical influences. 90% of transformer failures occur due to insulation breakdown [2].

This is true for power transformers, where there is a large accumulation of energy in the electromagnetic field of the circuit, which does not change instantly and directly affects the turn-on current. The more stored energy, the longer the overcurrent decays. From this it follows that the time of the alternating mechanical influences will pass for a rather long time, thereby deteriorating the insulating properties of the transformer winding. Therefore, when designing and operating transformers, it is necessary to take into account their properties in transient modes.

Thus, knowledge of the characteristics of transformers and the study of their dynamic processes is an urgent scientific and technical problem. Its solution will allow at the design stage to predict the magnitude of overcurrents when the transformer is turned on.

Materials and methods

To analyze the process of magnetization of a single-phase transformer in no-load mode without taking into account losses in steel, we will use the differential equation of state for the primary winding [3] (Fig. 1).

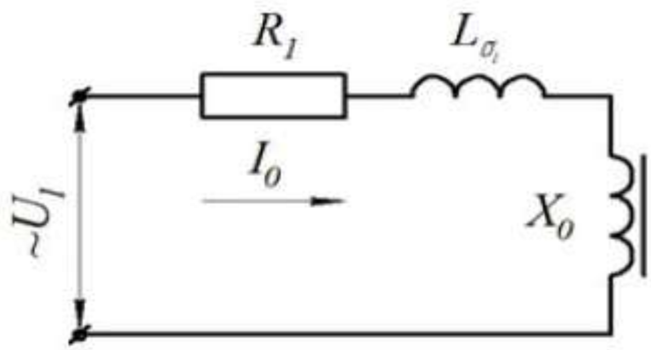

Fig. 1. Electrical circuit of the transformer in idle mode

Discussion

In fig. 1 shows the electrical equivalent circuit of the transformer in idle mode, where: R1 is the active resistance of the primary winding; Lσ1 — leakage induction of the primary winding; X0 — inductive reactance of the primary winding; U1 — input sinusoidal voltage of the primary winding; I0 — no-load current.

$$R_1 i_1 + L_1 \frac{di_1}{dt} + w_1 \frac{d\Phi}{dt} = u \qquad (1),$$

The equation for the magnetic circuit is based on the total current law (Kirchhoff's second law for the magnetic circuit)

$$Hl = \sum F = F_1 + F_2 = w_1 i_1 + w_2 i_2 \quad (2),$$

The magnetic field strength in the core is approximated by hyperbolic sine

$$H = \alpha \cdot \mathrm{sh}(\beta B) \quad (3),$$

Let us express the magnetic induction in the core through the flux

$$B = \frac{\Phi}{Q} \quad (4),$$

where Q is the section of the bar steel. Taking into account (2), (3), (4), we obtain

$$\alpha l \frac{\beta}{Q} \mathrm{sh}\left(\frac{\beta \Phi}{Q}\right) = w_1 i_1 + w_2 i_2 \quad (5),$$

Differentiating equation (5), we obtain

$$\alpha l \frac{\beta}{Q} \mathrm{ch}\left(\frac{\beta}{Q}\right) = w_1 \frac{di_1}{dt} + w_2 \frac{di_2}{dt} \quad (6),$$

Since at idle speed $i_2 = 0$, we get

$$\alpha l \frac{\beta}{Q} \mathrm{ch}\left(\frac{\beta}{Q}\right) = w_1 \frac{di_1}{dt} \quad (7),$$

where α and β are approximation coefficients; for steel grade 3405, 83.834 and 2,833 respectively.

Let us write the system of two differential equations (1) and (7) in the canonical form and solve the system of equations in matrix form. By solving these equations in the MathCad package, we will obtain oscillograms of the current and magnetic flux.

To create a computer model, we will use specific values calculated for a transformer of the type OM - 533 - 35 / 10.5 - U1 and TM - 1600 - 35 / 10.5 - U1 [4].

The calculation results are shown in Figures 2-5.

We will consider each phase of a three-phase transformer separately.

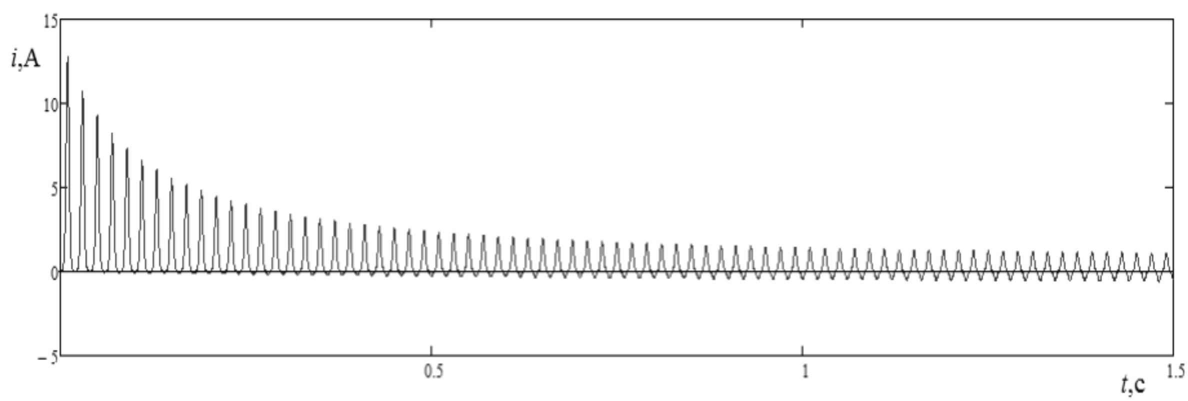

Fig. 2. Dependence of no-load current on time (single-phase transformer)

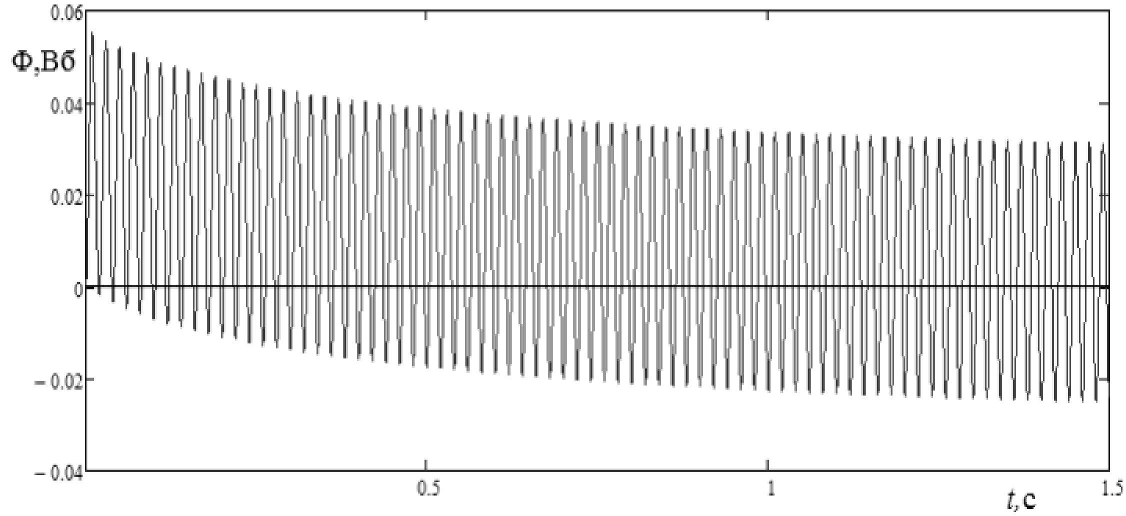

Fig. 3. Dependence of magnetic flux on time (single-phase transformer)

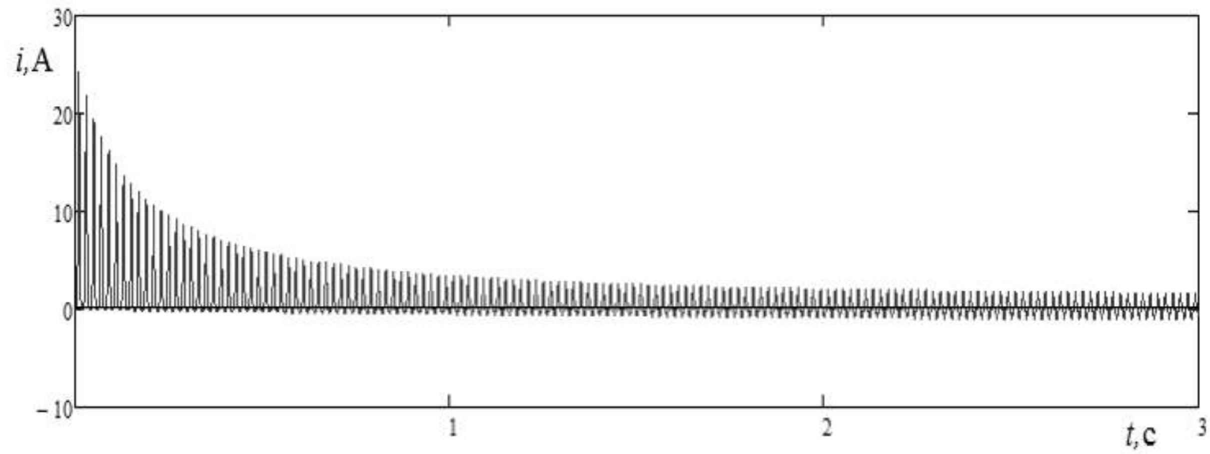

Fig. 4. Dependence of no-load current on time (three-phase transformer)

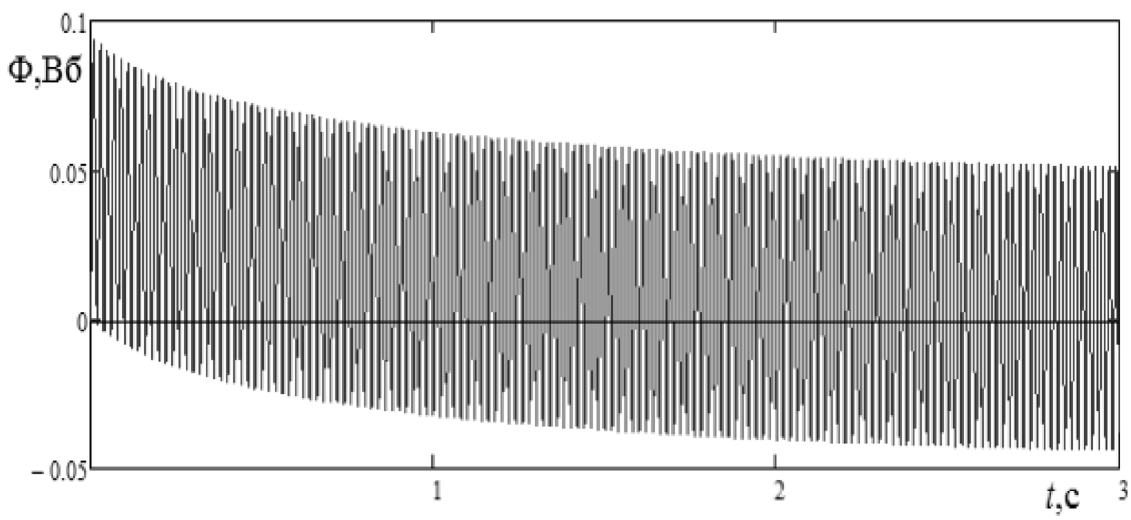

Fig. 5. Dependence of magnetic flux on time (three-phase transformer)

Conclusion

In a calculated single-phase transformer, the inrush current at the moment of switching on is 12.765 A, which is 84% of the nominal. The steady-state no-load current is 0.582 A and is reached after 1.5 seconds. In a three-phase transformer, the inrush current is 24.29 A, which is 92% of the nominal. The steady-state no-load current is 1.053 A and is reached after 3 seconds. In this case, the current does not exceed the nominal. The magnetic flux in a single-phase transformer reaches a value of 0.06 Wb, which is 1.4 times more than the nominal value, in a three-phase transformer 0.1 Wb, which is 1.44 times the nominal value.

Thus, when designing transformers, it is necessary to take into account the electromagnetic processes when switching on. Analysis of transient processes in a transformer allows you to make informed decisions in the development of its design and the formation of requirements for the operating conditions of the transformer and its protection means.

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