TYPES OF TRANSFORMER POWER LOSSES AND WAYS TO REDUCE THEM.

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Annotation. This article explores the different types of power losses in transformers and methods to minimize them. It provides a detailed explanation of nominal power, power factor, and the influence of load variations on transformer efficiency. The paper discusses core (steel) losses, copper (winding) losses, and the impact of idle operation. Practical ways to reduce losses—such as using high-quality electrical steel and optimizing winding design—are also reviewed. Additionally, the article outlines transformer design considerations aimed at achieving high efficiency under typical operating conditions.

Keywords. Transformer, power losses, efficiency, copper losses, core losses, load factor, no-load current, electromagnetic conversion, energy efficiency

Introduction

Nominal power. The nominal power of a transformer is the power that it can deliver for a long time without overheating above the permissible temperature. The normal operating life of a power transformer should be at least 20 years. Since the heating of the windings depends on the magnitude of the current flowing through them, the transformer passport always indicates the total power Snom in volt-amperes or kilovolt-amperes.

Depending on the power factor $\cos\varphi_2$ at which the consumers operate, more or less useful power can be obtained from the transformer. With $\cos\varphi_2$=l, the power of the consumers connected to it can be equal to the nominal power Snom.

When $\cos\varphi_2<1$ the power of the consumers should not exceed the value.

$$\frac{S_{nom}}{\cos\varphi_2}$$

Power factor. The power factor cosφ of a transformer is determined by the nature of the load connected to its secondary circuit. When the load decreases, the inductive resistance of the transformer windings begins to have a strong effect and its power factor decreases. In the absence of load (idle state), the transformer has a very low power factor, which degrades the performance of alternating current sources and electrical networks. In this case, the transformer must be disconnected from the AC network.

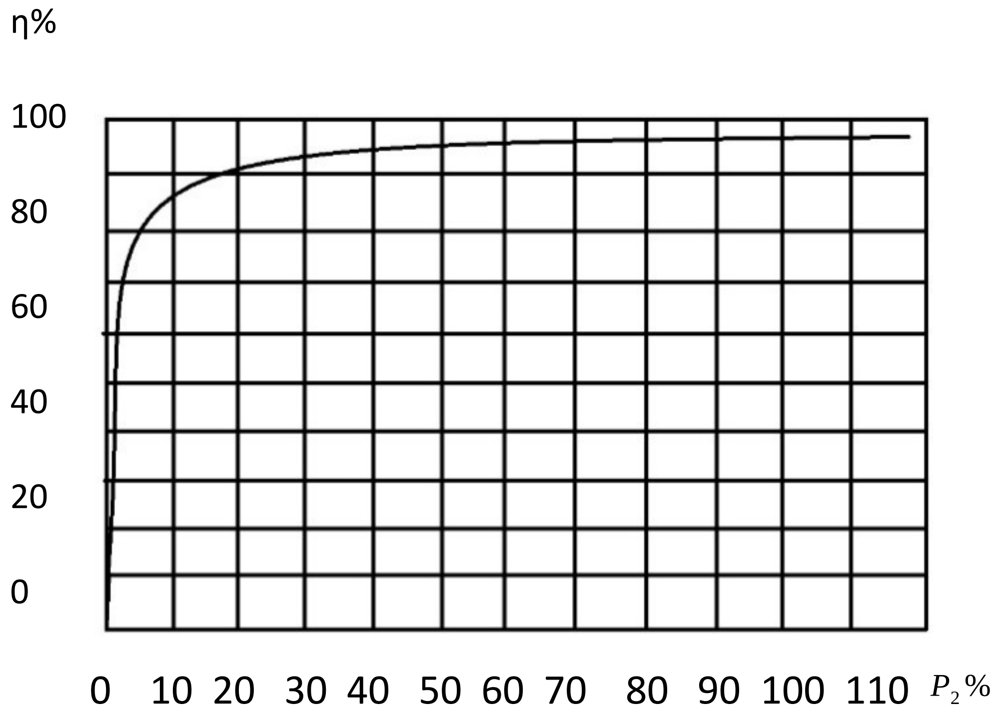

Figure 1. Dependence of transformer efficiency on load.

When idle, the transformer does not transmit electrical energy to the consumer. The power consumed by it is mainly spent on compensating for power losses due to currents in the magnetic circuit and hysteresis. The smaller the cross-section of the magnetic circuit, the greater the induction in it and, as a result, the lower the idle speed. They also increase significantly with an increase in the voltage applied to the primary winding above the nominal value. During operation of powerful transformers, no-load losses are 0.3-0.5% of its nominal power. However, they try to reduce them as much as possible. This is explained by the fact that steel losses do not depend on the transformer being idle or under load.

Since the total operating time of a transformer is usually very long, the total annual energy loss during downtime is an important value.

Electrical losses in the winding wires under load, no-load losses

$$\Delta P_{ез} = \Delta P_{ел1} + \Delta P_{ел2}$$

These losses at the rated current are equal to the power consumed by the transformer during a short circuit when the voltage Uк is applied to its primary winding. For high-power transformers, they are usually 0.5-2% of the rated power. To reduce total losses, the correct selection of the wire cross-section of the transformer windings (reducing electrical losses in the wires), the use of electrical steel for the manufacture of the magnetic circuit (reducing losses from magnetization reversal), and the division of the magnetic circuit into a number of sheets separated from each other (reducing losses from eddy currents).

Transformer efficiency equation:

$$\eta = \frac{P_2}{P_1} = \frac{P_2}{P_2 + P_{ел} + P_{ст}}$$

The efficiency of the transformer is relatively high and reaches 98-99% in high-power transformers. In low-power transformers, the efficiency can decrease to 50-70%. When the load changes, the efficiency of the transformer changes, since the useful power and electrical losses change. However, it remains significant over a fairly wide range of load changes (Fig. 2.1). With a large load, the efficiency decreases, since the useful power decreases, and the losses in the steel remain unchanged. A decrease in efficiency is also caused by overloads, since electrical losses increase sharply (they are proportional to the square of the load current, and the useful power is equal to the current only in the first order). The maximum value of the efficiency is at such a load, when the electrical losses are equal to the losses in the steel.

When designing transformers, they strive to achieve maximum efficiency at a load of 50-75% of the nominal; this corresponds to the most likely average load of the operating transformer. Such a load is called economic.

The proposed material discusses the principles and some subtleties of the process of converting electrical energy, how to avoid some mistakes when designing transformers, and also why the transformation ratio is not always a constant value.

Transformer - a static (without rotating parts) electromagnetic device that converts electrical energy of an alternating current with one voltage (current) value into electrical energy of another voltage (current) value at the same frequency. The simplest transformer consists of a core made of electrical steel, on which two windings I and II are installed (Fig. 2.2). The windings that, when connected to a network with a certain voltage, receive alternating current from it, for example, winding I, are called primary, and the other winding that supplies alternating current to another network or load, for example, winding II, are called secondary.

When an alternating current of a certain frequency is passed through the primary winding, the magnetic flux arising in the magnetic circuit crosses the turns of the secondary winding, inducing an electromotive force (EMF) in it, which, when the winding is short-circuited to any circuit, the appearance of an alternating current of the same frequency in the load .Since the magnetic flux in its change simultaneously crosses the turns of the energized primary winding, an electromotive force is induced in it, which coincides in phase with the electromotive force induced in the secondary winding.

No-load current. When the secondary winding is open (the secondary circuit is disconnected), the current in the primary winding is minimal and the winding can be considered as a simple induction coil with a ferromagnetic core. In this case, the electromotive force in the primary winding, or the so-called primary electromotive force [1], is:

$$E_1 = 4{,}44 * F_m * f * W_1 * 10^{-8}$$

The current flowing in the primary winding with the secondary circuit open is very small, and the voltage loss generated in this winding is also very small, so we can assume that the primary electromotive force is almost equal and opposite to the voltage U1, i.e. E1 = U1 and therefore:

$$U_1=4,44*F_m*f*W_1*10^{-8}$$ [2].

Here, it is immediately necessary to clarify that the current in the winding connected to an external source of alternating voltage, with the terminals of the secondary winding open, will be small only if the condition is met:

$$U * Z = \{A / B_m * Q_c\} * U$$

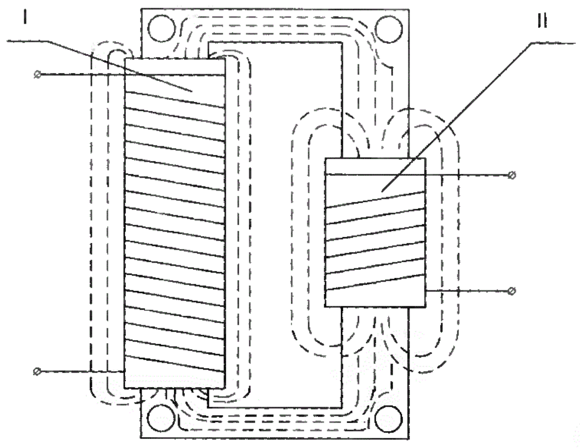

Figure 2 The simplest transformer diagram

where A is some empirical number, the value of which can be from 40 to 60 (most often, the value of 50 is used in calculations). This number depends on the grade of transformer steel (E41-E43 - isotropic hot-rolled, E310-E330 - textured cold-rolled, E340-E360 - textured cold-rolled with reduced conductivity, etc.), the shape of the core (Sh, ShL) , P, PL, O, etc.), the manufacturing technology and the quality of the core assembly. The correctness of this statement can be easily demonstrated, for example, by disassembling a core assembled from W-shaped plates and then "forgetting" some of the plates during assembly. The "no-load" current of such a transformer at a constant voltage applied to the primary winding increases significantly.

For the secondary electromotive force, i.e. the electromotive force induced in the secondary winding, consisting of W2 turns and intersected by the same magnetic flux Fm, one can consider:

$$E_2 = 4{,}44 * Ф_м * f * W_2 * 10^{-8}$$

And since E2=U2 and formulas (2) and (2a) differ only in the number of turns W1 and W2, the transformation ratio is considered equal to the ratio of the turns of the primary and secondary windings:

K = W1. /W2.

The value of the maximum magnetic flux in the "idle" state of the transformer is equal to:

Fм = (E * 108) /(4,44 * f * W1)

When the transformer is loaded, that is, connect some resistance to its secondary winding, then the current strength in the primary winding increases, the voltage loss in it also increases, therefore, with a constant primary voltage at the terminals, the primary electromotive force E and, consequently, the magnitude of the magnetic flux Fm should decrease.When the transformer is loaded, since the secondary current causes the demagnetization effect mentioned above, it can be assumed that when the load is connected, a power flow enters the primary circuit, which approximately restores the magnetic flux [1].When the transformer is operating with a load, the entire power consumed by the primary winding P1 is spent on the useful power P2 in the secondary circuit and on losses consisting of losses in the transformer itself (iron). In the magnetic circuit and in the copper windings. Hence, the efficiency:

$$\eta = P2/ P1$$

As noted above, the maximum magnetic flux entering the transformer windings practically does not change when the load changes, therefore, the losses in the transformer core can be considered constant and the same for both "no-load" and operating transformers. load.

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