ГОДИШНИК на Минно-геоложкия университет "Св. Иван Рилски", Том 51, Св.III, Механизация, електрификация и автоматизация на мините, 2008
ANNUAL of the University of Mining and Geology "St. Ivan Rilski", Vol. 51, Part III, Mechanization, electrification and automation in mines, 2008

NO-LOAD RUNNING OF ELECTRIC TRANSFORMERS

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ABSTRACT: By the no-load running of electric transformers we understand that service where electric power is not released through the transformer to consumers, the transformer secondary winding being open reason why the power in this winding is zero (i_2=0).

Key words: Electric transformer, magnetic flow, vectorial diagram, magnetic field, parameters, no-load running, transformation report.

РАБОТА БЕЗ НАТОВАРВАНЕ НА ЕЛЕКТРИЧЕСКИТЕ ТРАНСФОРМАТОРИ
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Резюме: Под работа без натоварване на електрически трансформатор разбираме това обслужване, когато електрическата енергия не се отделя през трансформатора за консуматорите, вторичната намотка на трансформатора е отворена и по тази причина мощността в тази намотка е нула (i2=0).
Ключови думи: Електрически трансформатор, магнитен поток, векторна диаграма, магнитно поле, параметри, експлоатация без натоварване, трансформиране.

Introduction

Due to the fact that the secondary winding is open (i_2=0), in this status the transformer is a magnetic core coil connected to the nominal u_1 voltage rating**.** The presence of two windings causes the decomposition of the magnetic flow, created by the primary winding of the transformer, in two flows – the main magnetic flow Φ_0 and the dispersion flow $\Phi_{\sigma 1}$. The flow Φ_0 is a mutual induction flow closed through the magnetic core and inducing in the primary and secondary windings of the transformer, accordingly t.e.m. Of self-induction E_1 and t.e.m. Of mutual induction E_2, displaced after (Φ_0) by 90°.

The equation of no-load running of electric transformers

The dispersion flow $\Phi_{\sigma 1}$ and magnetic flow Φ_0 are created by one and the same t.m.m. $w_1 i_{10}$**,** and the flow is $\Phi_{\sigma 1}$ much lower than Φ_0. This happens because $\Phi_{\sigma 1}$ closes through the air, meaning through the environment with a high magnetic reluctance and that is why in the case of no-load running it is only around 0,25% from Φ_{0m}. Besides, the flow Φ_0 is split with the established angle α comparing to t.m.m. $w_1 i_{10}$ **(**comparing to the current i_{10} respectively), due to the losses through eddying flows and hysteresis from the magnetic circuit (the transformers magnetic core). Due to the absence of the losses in the air $\Phi_{\sigma 1}$, the flow is in phase with t.m.m $w_1 i_{10}$ (with the current i_{10} respectively).

The dispersion flow $\Phi_{\sigma 1}$ connects only to the spirals of primary winding and induces in it dispersion t.e.m., established by the relation:

$$e_{\sigma 1} = -w_1 \frac{d\Phi_{\sigma 1}}{dt} = -\frac{d\psi_{\sigma 1}}{dt} \tag{1}$$

This is self-induction t.e.m. $e_{\sigma 1}$. The total dispersion flow $\psi_{\sigma 1}$ is in proportion with the no-load running current i_{10}**,** meaning:

$$\psi_{\sigma 1} = L_{\sigma 1} \cdot i_{10} \tag{2}$$

where it results:

$$e_{\sigma 1} = -L_{\sigma 1} \cdot \frac{di_{10}}{dt} \tag{3}$$

where:

$L_{\sigma 1}$ - primary winding dispersion inductivity. Inductivity $L_{\sigma 1}$ is constant in size, because the flow $\Phi_{\sigma 1}$ is closed through air.

T.e.m. Induced by the dispersion flow adequately causes the inductive fall of equal voltage and opposed to it in sign, meaning $e_{\sigma 1} = -u_L$. If we apply the symbolic method we get:

$$\underline{E}_{\sigma 1} = -\underline{U}_{L1} = -jX_{\sigma 1}\underline{I}_{10} \tag{4}$$

where:

$X_{\sigma 1}$ - dispersion reactance of primary winding.

Primary winding has active resistance R_1. In this case, if R_1 and $X_{\sigma 1}$ are known, we can establish the equivalent scheme of the transformer for the no-load running, which contains only the parameters of primary winding (fig.1).

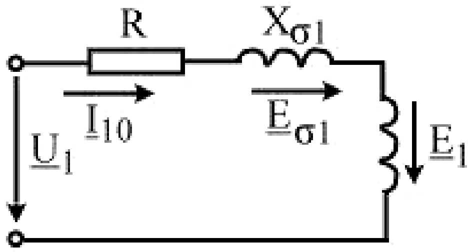

Fig.1 The equivalent scheme of the transformer at the no-load running which contains only the parameters of primary winding

If we introduce the i_{10} equivalent sinusoidal current, in the equivalent scheme, according to Kirchhoff's 2nd law, we establish the equilibrium equation of t.e.m. Momentary values and voltage drops:

$$e_1 + e_{\sigma 1} = R_1 i_{10} - u_1 \quad (5)$$

where it results that:

$$u_1 = -e_1 - e_{\sigma 1} + R_1 i_{10} \quad (6)$$

By representing in complex, the equation (6) in complex form becomes:

$$\underline{U}_1 = -\underline{E}_1 - \underline{E}_{\sigma 1} + R_1 \underline{I}_{10} \quad (7)$$

After replacing the relation (4) in the equation (3.7) we get:

$$\underline{U}_1 = -\underline{E}_1 + R_1 \underline{I}_{10} + jX_{\sigma 1}\underline{I}_{10} = -\underline{E}_1 + \underline{I}_{10}(R_1 + jX_{\sigma 1}) = -\underline{E}_1 + \underline{Z}_1 \underline{I}_{10} \quad (8)$$

where:

$\underline{Z}_1 = R_1 + jX_{\sigma 1}$ - total complex impedance of primary winding.

Equation (8) allows to build the vectorial diagram of the transformer at the no-load running, which is the graphic solution of this equation (fig.3).

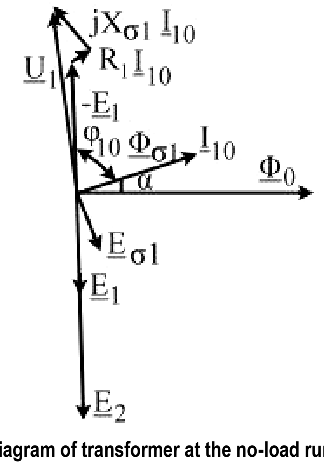

Fig.2 Vectorial diagram of transformer at the no-load running

The vectorial diagram construction begins at the main magnetic flow phasor Φ_0. With an angle of 90° we traced behind the phasor Φ_0, the t.e.m. Induced E_1 şi E_2. The current I_{10} is split before the magnetic flow Φ_0 with an angle α due to energy losses in the magnetic core and is in the phase with the dispersion flow $\Phi_{\sigma 1}$, which mainly closes through the air, where there are no losses. The 90° angle helps tracing the flow phasor $\Phi_{\sigma 1}$ the t.e.m. Dispersion phasor is traced $E_{\sigma 1}$. Further, for getting the voltage phasor $\underline{U}_1$, it is necessary to continue the construction, which represents the equation graphic solution (8).

For this purpose, the phasor representing t.e.m. E_1, is built reversely (E_1 in the equation 8 has the minus sign), and it is added the phasor of voltage active drop $R_1 I_{10}$ on the resistance R_1 and the phasor of the voltage reactive drop $X_{\sigma 1} I_{10}$ on the dispersion reactance $X_{\sigma 1}$. The Voltage drop $R_1 I_{10}$ is in the phase with the current I_{10}, and the drop is $X_{\sigma 1} I_{10}$ split before by 90°. The phasor of the voltage reactive drop $X_{\sigma 1} I_{10}$ equals the phasor representing $E_{\sigma 1}$ in size and sense.

From the vectorial diagram, we notice that the phase difference between the U_1 voltage and the current I_{10} almost equals 90°. Consequently, the ***no-load running transformer can be analyzed as an almost purely inductive character consumer, which makes the network power factor stronger.*** We have to underline that the no-load running current is much lower than the I_{1n} nominal current meaning $I_{10} = (3 \div 10)\% I_{1n}$.

If we take into consideration te low value of the no-load running current and that active resistances of the transformer windings are much lower (three times lower than the reactance), we notice that in comparison with t.e.m. E_1 voltage drop is $R_1 I_{10}$ visibly lower. Secondly, $\Phi_{\sigma 1}$ is around 0,25% Φ_{0m}, so that $\underline{E}_{\sigma 1} = -jX_{\sigma 1}\underline{I}_{10} << \underline{E}_1$. In this case, the voltage drops on the resistance and the reactance of primary winding reactance, can be neglected and the equation (8) has the form:

$$\underline{U}_1 \approx -\underline{E}_1 \quad (9)$$

meaning for the no-load running, the U_1 voltage is balanced almost entirely with t.e.m. E_1. Considering these, in fig.3 it is presented the simplified vectorial diagram of the transformer in the no-load running.

t.e.m. E_1 and E_2 phasors are in phase, because they are induced by one and the same magnetic flow Φ_0. The difference between their sizes is due to the number of curls included in the primary and secondary windings.

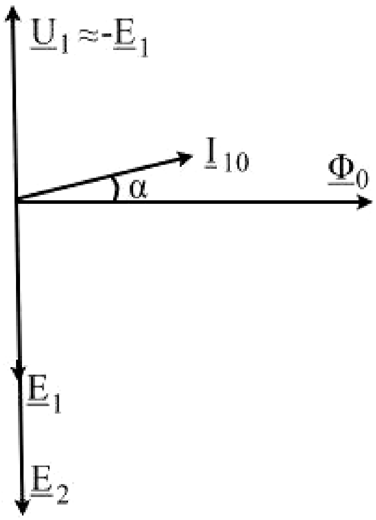

Fig.3 Transformer simplified vectorial diagram in the no-load running

Because in the no-load running no current passes through the transformer secondary winding, voltage drop cannot be obtianed. Therefore, the voltage measured at the terminals of the secondary winding equals induced t.e.m., meaning:

$$\underline{U}_{20} = \underline{E}_2 \qquad (10)$$

If we consider the equalities (9) and (10) for the transformation report, we get:

$$k = \frac{E_1}{E_2} = \frac{w_1}{w_2} \approx \frac{U_1}{U_{20}} \qquad (11)$$

The experimental establishment of the transformation report is based on this dependence. From the same dependence (11) it results that in the no-load running, the transformer can be used for the transformation in a relatively exact report of high voltages into lower voltages for measuring them with common voltmeters. The transformers specially built for this are called voltage measurement transformers. In practice, very often, besides these transformers in high voltage circuits, different protection or control devices are also included.

Conclusions

In the no-load running status, the transformer can be examined by the consumer with an almost inductively character which makes the network power factor worse. Due to the low power factor $\cos\varphi_{10}$ and the low current at the no-load running I_{10}, the active power P=UI $\cos\varphi_{10}$ consumed by the transformer in this service is low. Because in the no-load running service the transformer does not release power to consumers (I_2=0), it results that ***the active power P_{10} absorbed from the network is lost in the transformer, meaning P_{10} represents the active power losses in the transformer at the no-load running.***

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