

ON-LINE DIAGNOSTICS OF MECHANICAL DEFORMATIONS OF WINDING

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The important diagnostic parameter of transformer condition is the short circuit resistance Z_s . Deviation of this parameter enables to estimate the level of winding mechanical condition. However for its detection it is necessary, that the transformer has been disconnected and conditions of short circuit test are created. This fact reduces opportunities of operative diagnostics. Therefore there is a necessity of creation of on-line method of detection of the winding deformation. Here such method is described.

The system of the transformer equations looks like:

$$\begin{cases} U_1 = Z_{11}I_1 + Z_{12}I_2 \\ U_2 = Z_{21}I_1 + Z_{22}I_2 \end{cases} \quad (1)$$

Here U_1, U_2 - effective values of voltages of windings; I_1, I_2 - effective values of currents of windings; Z_{ij} – the coefficients at the currents, which have the resistance dimension ($i, j = 1, 2$).

The system of the transformer equations can be written down for the currents:

$$\begin{cases} I_1 = Y_{11}U_1 + Y_{12}U_2 \\ I_2 = Y_{21}U_1 + Y_{22}U_2 \end{cases} \quad (2)$$

Here coefficients at voltage Y_{ij} have admittance dimension. There are also other forms of the transformer system of the equations of [1].

The equations (1), (2) can be represented in the matrix form, which is more convenient for the analysis and calculations:

$$\begin{bmatrix} U_1 \\ U_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} \quad (1a)$$

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} \begin{bmatrix} U_1 \\ U_2 \end{bmatrix} \quad (2a)$$

Where the vectors of voltages U and currents I are connected among themselves through square matrices of coefficients Z or Y .

The system of the equations describes an equivalent circuit (electrical model). There are few electrical models, two of which are shown on fig. 1. If the electrical model parameters Z_i, Y_i (or coefficients Z_{ij}, Y_{ij} , etc.) are known, it is possible to calculate transformer short circuit resistance Z_{sc} :

$$Z_{sc} = \begin{cases} Z_1 + Z_2 Z_3 / (Z_2 + Z_3) \\ 1 / (Y_1 + Y_3) \\ Z_{11} - Z_{12} Z_{21} / Z_{22} \\ 1 / Y_{11} \end{cases}$$

We can see, that finding of one element of matrix Y is the most efficient decision.

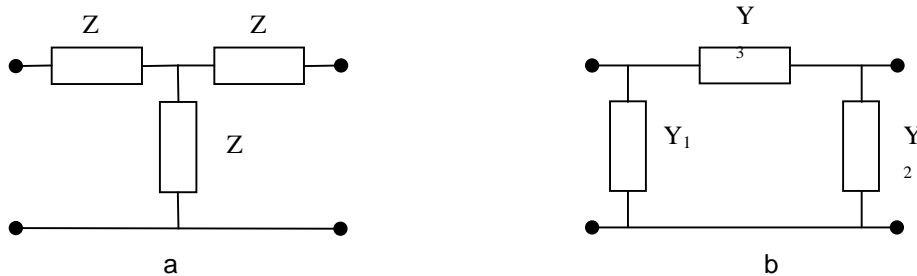


Fig.

For the calculation of four coefficients $Z_{11}, Z_{12}, Z_{21}, Z_{22}$ (or one Y_{11}) it is necessary to form two systems of the equations (1), (1 a) (or (2), (2a)):

$$(1) \quad \begin{cases} U'_1 = Z_{11} I'_1 + Z_{12} I'_2 \\ U'_2 = Z_{21} I'_1 + Z_{22} I'_2 \end{cases}$$

and

$$(1'') \quad \begin{cases} U''_1 = Z_{11} I''_1 + Z_{12} I''_2 \\ U''_2 = Z_{21} I''_1 + Z_{22} I''_2 \end{cases}$$

Where U'_1, U'_2, I'_1, I'_2 - values of voltages and currents corresponding to one value of loading, and $U''_1, U''_2, I''_1, I''_2$ - values of voltages and currents corresponding to other value of loading. Having united the systems (1') and (1'') and having solved the new united system, we shall obtain values of coefficients. In a matrix form this solution looks so:

$$\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} = \begin{bmatrix} U'_1 & U''_1 \\ U'_2 & U''_2 \end{bmatrix} \begin{bmatrix} I'_1 & I''_1 \\ I'_2 & I''_2 \end{bmatrix}^{-1}$$

Or in the unwrapped kind:

$$\begin{aligned} Z_{11} &= (U'_1 I''_2 - U''_1 I'_2) / (I'_1 I''_2 - I''_1 I'_2) \\ Z_{12} &= (-U'_1 I'_1 + U''_1 I'_1) / (I'_1 I''_2 - I''_1 I'_2) \\ Z_{21} &= (U'_2 I''_2 - U''_2 I'_2) / (I'_1 I''_2 - I''_1 I'_2) \\ Z_{22} &= (-U'_2 I''_1 + U''_2 I'_1) / (I'_1 I''_2 - I''_1 I'_2) \end{aligned}$$

ACCOUNT OF NON-LINEARITY OF THE TRANSFORMER

However the resistance found by the described way, is not equal to the resistance measured in short circuit test. It takes place owing to non-linearity of the transformer. In the operating conditions the core of the transformer is saturated, and in the short circuit test conditions is not saturated. It results in nonlinear change of dissipation field parameters though in the classical theory of transformers that parameters are considered linear. Lets show physical bases for this non-linearity.

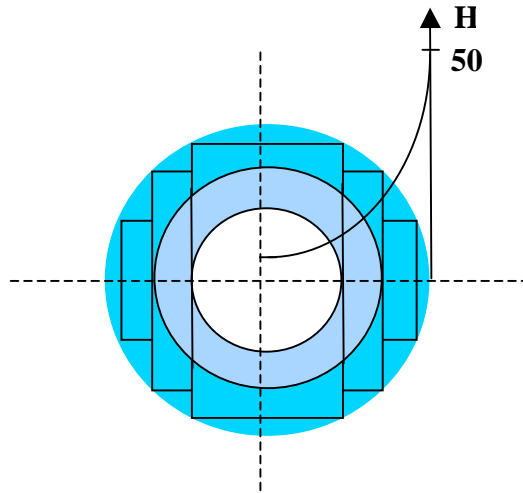


Fig.2

The core saturation of operating transformer is distinctly not uniform. Extreme packages are deep saturated, while central packages have little saturation (fig.2). Parameters of saturated domains are practically linear and their magnetic resistance is much higher, than resistance of non-saturated domains. It weakens a resulting dissipation magnetic flow in comparison to dissipation flow at short circuit, and reduces the transformer equivalent electric resistance Z_t . As according to theory the transformer equivalent electric resistance in loaded condition is considered to be practically equal to short circuit resistance Z_s , as a result we have error, that can reach 100% and more. Thus, for determination of correct value Z_s it is necessary to approximate the calculated value $Z_{sc} = Z_t$ to conditions of short circuit test. Such approximation can be performed by multiplying Z_{sc} on coefficient of non-linearity χ ($\chi Z_{sc} = Z_s$). To find coefficient of non-linearity it is possible according to measurements of instant values of currents and voltages:

1. According to measurement data we shall plot Veber-Ampere loop relationship (VAR) for one period of current and voltage variation (fig.3).
2. One-valued (not loop) VAR for instant values is found by calculation (fig.3).
3. Volt-Ampere relationship for effective values is determined by calculation (fig.4).
4. The coefficient of non-linearity χ is calculated by two points of Volt-Ampere relationship.

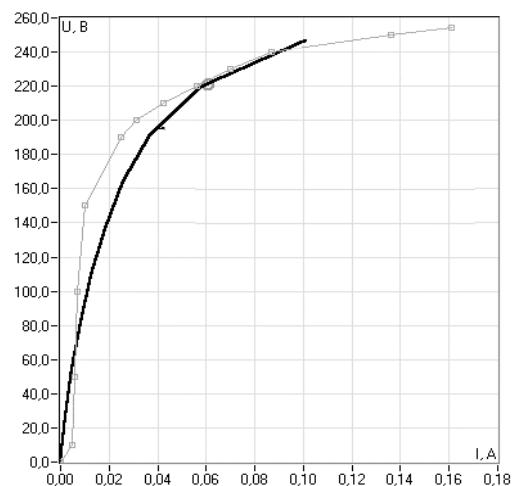


Fig.3

Fig.4

Estimation of the error

The error of the method of finding Z_{sc} can be counted to the equal sum of errors of instrument current and voltage transformers. At approximation Z_{sc} to conditions of short circuit test the computing error of determination of coefficient of non-linearity is added.

Conclusion

The method on-line diagnostics of winding mechanical deformation of transformers is described.

References

P.A. Butyrin, M.E. Alpatov, The Continuous Diagnostics of Transformers// Electrical Technology Russia, Publ. JSC "Znack", 1998, #3, p. 23-42.