UNBALANCED OPERATION OF TRANSFORMERS AND ELECTRICAL ENERGY LOSSES

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Abstract – In the paper is presented a useful method for electric energy losses evaluation in two-winding transformers. An adequate mathematical model for the case of several transformers working within the same power station is developed, by supposing an unbalanced transformers load.

Keywords: unbalance load, electrical electrical efficiency, electrical power.

1. INTRODUCTION

In distribution grids two components (namely, technical and commercial) of the energy losses can by studied. Technical component consists of two sub-classes, i.e. the real and the theoretical one. Having in vue that the technical component of energy losses could be minimized, it follows that electric energy losses may represent an index characterizing the operating performance of a distribution network.

2. INPUT DATA AND LOAD INDEXES

Usually, the input information necessary to compute the energy losses in a power station (PS) concerns the rated transformer characteristics and the PS topology.
The rated characteristics of the transformer are: S_{nk} – apparent rated power of T_k transformer; P_{ok} – no-load power losses; P_{sck} – short-circuit power losses; i_{ok} - the no-load percentage current; u_{sck} – the short-circuit percentage voltage.

By supposing that one have information, at the low voltage level voltage, concerning U, current I, real power P or real energy W_a, reactive power Q or reactive energy W_r, all at equally-spaced time intervals Δt, one can evaluate the load indexes.

The most used are:
- average total power S_{med}:

$$S_{med} = \frac{\sqrt{W_a^2 + W_r^2}}{t_f} \qquad (1)$$

where: W_a is real energy

$$W_a = W_{aA} + W_{aB} + W_{aC} \qquad (2)$$

and W_r - reactive energy

$$W_r = W_{rA} + W_{rB} + W_{rC} \qquad (3)$$

In the above relations: W_{aA}, W_{aB}, W_{aC} are average operational active energy and W_{rA}, W_{rB}, W_{rC} are average operational reactive energy by phase of transformer T_k,.

- fill-up coefficient k_u:

$$k_{uS} = \frac{S_{med}}{S_{\max}} \qquad (4)$$

where: S_{max} is the maximum total power, while t_f is the operating time of customer.

- time wastage uttermost τ, evaluate by

$$\tau = t_f \cdot \left[a \cdot k_u^2 + (1-a) \cdot k_u\right] \qquad (5)$$

where: *a* is coefficient for maximum total power $a \in [0{,}1\ ;\ 0{,}3]$, while t_f is the operating time of the customer.

3. ELECTRIC POWER LOSSES IN TRANSFORMERS

Using the relations for a single-phase transformer energy losses, one can write for symmetrically built three-phase transformer the following equations:

- active energy losses ΔW_{ak}

$$\Delta W_{ak}^{sym} = \left[P_{ok} + P_{sck} \cdot \left(\frac{U_n}{S_{nk}}\right)^2 \cdot \left(\frac{S_{med}}{U_{med}}\right)^2\right] \cdot t_f \qquad (6)$$

- reactive energy losses ΔW_{rk}

$$\Delta W_{rk}^{sym} = \left[Q_{ok} + Q_{sck} \cdot \left(\frac{U_n}{S_{nk}}\right)^2 \cdot \left(\frac{S_{med}}{U_{med}}\right)^2\right] \cdot t_f \qquad (7)$$

In the case of unbalanced loads it is needful to use the symmetrical components. In such a case it is possible to calculate the current zero and negative factors as:

$$k_I^o = \frac{I^o}{I^+} \qquad \text{zero factor} \qquad (8)$$

$$k_I^- = \frac{I^-}{I^+} \qquad \text{negative factor} \qquad (9)$$

Now it is possible to define the positive sequence total power as:

$$S_k^+ = \sqrt{3} \cdot U_n \cdot I^+ \qquad (10)$$

Noting by:

$$\alpha_{Sk} = \frac{S_k^+}{S_{nk}} \qquad (11)$$

the total power loading coefficient and using the above relations, the equations (6) and (7) become:

$$\Delta W_{ak}^{nes} = \left\{P_{ok} + P_{sck} \cdot \left[1 + \left(k_I^o\right)^2 + \left(k_I^-\right)^2\right] \cdot \alpha_{Sk}^2\right\} \cdot t_f \qquad (12)$$

$$\Delta W_{rk}^{nes} = \left\{Q_{ok} + Q_{sck} \cdot \left[1 + \left(k_I^o\right)^2 + \left(k_I^-\right)^2\right] \cdot \alpha_{Sk}^2\right\} \cdot t_f \qquad (13)$$

or:

$$\Delta W_{ak}^{nes} = \Delta W_{a\,ok} + \Delta W_{a\,sck} \cdot \alpha_{Sk}^2 \cdot \left[1 + \left(k_I^o\right)^2 + \left(k_I^-\right)^2\right] \qquad (14)$$

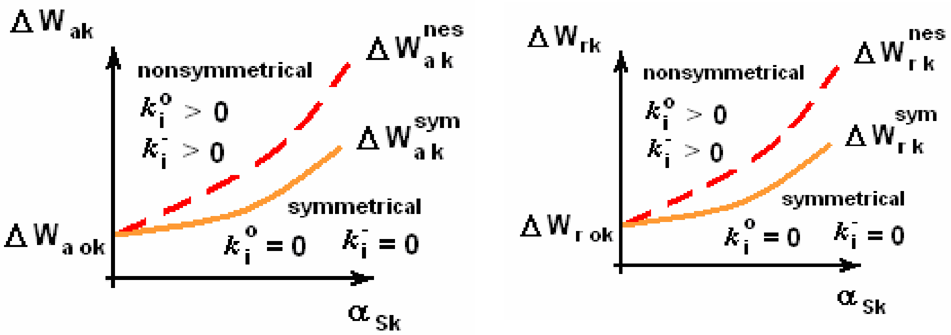
$$\Delta W_{rk}^{nes} = \Delta W_{r\,ok} + \Delta W_{r\,sck} \cdot \alpha_{Sk}^{2} \cdot \left[1 + \left(k_I^{o}\right)^2 + \left(k_I^{-}\right)^2\right] \qquad (15)$$

where:

$$\Delta W_{a\,ok} = P_{ok} \cdot t_f \text{ and } \Delta W_{r\,ok} = Q_{ok} \cdot t_f \qquad (16)$$

$$\Delta W_{a\,sck} = P_{sck} \cdot t_f \text{ and } \Delta W_{r\,sck} = Q_{sck} \cdot t_f \qquad (17)$$

The functions $\Delta W_a^{nes} = f(\alpha_{Sk})$ and $\Delta W_r^{nes} = f(\alpha_{Sk})$ are presented in figure 1.



a. active energy losses ΔW_{ak} b. reactive energy losses ΔW_{rk}

Fig.1. Energy losses ΔW_{ak} and ΔW_{rk} operating regime

4. SOME RESULTS

The presented model has been used to evaluate the losses corresponding to a two transformer PS configurations, with characteristics given in table 1.

Table 1. Equipment characteristics and loading scenarios for transformer 25kVA

U_{np}[kV]	20	k_I^-	k_I^o
U_{ns}[kV]	0,4	0	0
P_o[kW]	0,175	0,06	0,06
P_{sc}[kW]	0,957	1,59	1,59
i_o[%]	2	2,01	2,01
u_{sc}[%]	6		

The power losses variation, as a function of the total power loading coefficient, for the case a 25kVA PS, is presented in fig.2, for symmetrical regime.
For the same PS configuration the active energy losses variation, as a function of no symmetrical coefficients $k_I^- = k_I^o = 0{,}06$ are presented in figure 3, for $k_I^- = k_I^o = 1{,}59$ in the figure 4.

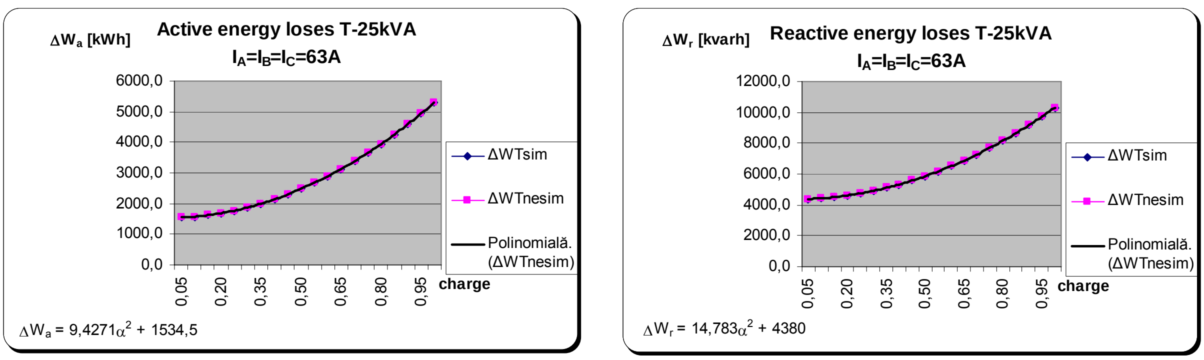


Fig. 2. Active and reactive power losses as function of symmetrical regime for transformer – 25kVA

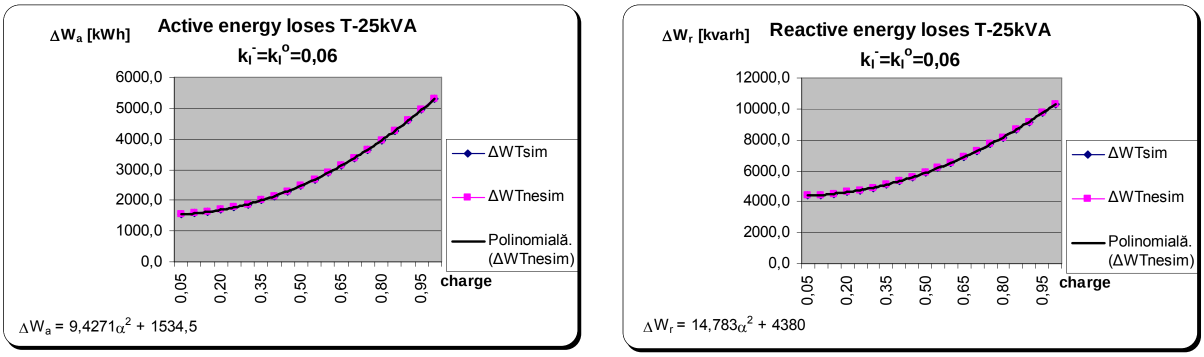


Fig. 3. Active and reactive power losses as function of non-symmetrical regime case $\mathbf{k_I^- = k_I^o = 0,06}$ for transformer – 25kVA

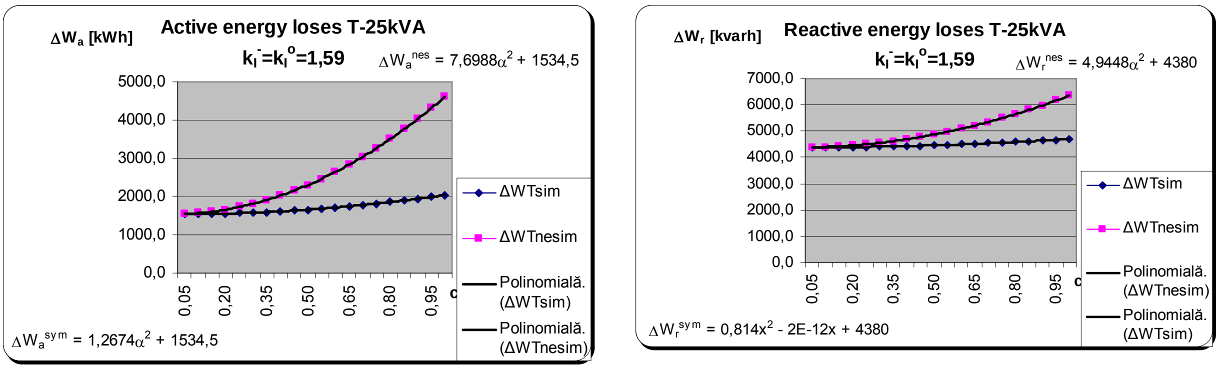


Fig. 4. Active and reactive power losses as function of non-symmetrical regime case $\mathbf{k_I^- = k_I^o = 1,59}$ for transformer – 25kVA

5. CONCLUSIONS

The presented model allows estimating the energy losses in unbalanced operation of transformers. In is worth to underline that such operation produces a diminution in the efficiency of the electricity. Thus, for the sake of increasing the economic efficiency of the distribution industry, several technical measures are recommended.

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