Determination of Optimal Load Factors for Transformers of Distributive Electrical Networks

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Optimal or near optimal transformers loading of distributive power networks can be achieved with two main ways. The first one is based on the calculation of optimal load and connecting this load to the transformer. The second way implies replacement of existing transformers with new ones, having optimal nominal power. The aim of this research is to developed model to determine optimal load factor for transformers.

The minimum of relative cost of electric energy transmission C_t was used as optimal criterion:

$$C_t = \frac{S}{W}, \tag{1}$$

where

S – total cost of electrical energy transmission,$;

W – quantity of electrical energy, transmitted to consumers, kWh.

First of all instead of original network the authors explored the network equivalent to it. This equivalent network consists of two resistors connecting in series and have the same energy losses, which lines and transformers of original network have. Optimal load factor k_c for this equivalent network can be calculated using the following equation:

$$k_c = \sqrt{\frac{pK + \Delta W_n \cdot \beta}{\Delta W_l \cdot \beta}}, \tag{2}$$

where

pK – annual operation and repair cost,$;

ΔW_n – annual non-load energy losses, kWh

β – electric energy tariff, $/kWh;

ΔW_l – annual load energy losses, kWh.

To use equation (2) to the single transformer isn't correct, because k_c meansoptimal loading of the whole network. Obviously, k_c and optimal load factor for single transformer may be different. That is why, it's necessary to calculate optimal load factor for each single transformer of the network.

Mathematical model to determine optimal load factor represents system, consisting of n equations, where n – number of transformers. After simple transformation, this system has form (3).

$$\begin{cases} \left[k_1 \cdot S_1 \cdot T_1 \cdot \sum_{j_1=1}^{m_1} r_{j1}\right] \times \frac{1}{\cos\varphi_1} = \left[k_2 \cdot S_2 \cdot T_2 \cdot \sum_{j_2=1}^{m_2} r_{j2}\right] \times \frac{1}{\cos\varphi_2}; \\ \left[k_2 \cdot S_2 \cdot T_2 \cdot \sum_{j_2=1}^{m_2} r_{j2}\right] \times \frac{1}{\cos\varphi_2} = \left[k_3 \cdot S_3 \cdot T_3 \cdot \sum_{j_3=1}^{m_3} r_{j3}\right] \times \frac{1}{\cos\varphi_3}; \\ \ldots\ldots \\ -E + \frac{\beta}{\cos\varphi_i}\left[2k_i \cdot S_i \cdot T_i \cdot \sum_{j_i=1}^{m_i} r_{ji}\right] \times \sum_{i=1}^{n}(k_i \cdot S_i \cdot T_i \cdot \cos\varphi_i) - \beta \cdot F(k_i) + \\ 2 \cdot \frac{\beta}{\cos\varphi_i}\left[\sum_{j=1}^{m} r_{ji} \cdot \sum_{i_j=1}^{n_j} k_{3i_j} \cdot S_{i_j} \cdot T_{i_j}\right] \times \sum_{i=1}^{n}(k_i \cdot S_i \cdot T_i \cdot \cos\varphi_i) - \beta \cdot G(k_i) = 0 \end{cases} \tag{3}$$

where

m – total number of lines and transformer summary;

k_i, – optimal load factor of the *i*-th transformer;
S_i – nominal power of the *i*-th transformer, kVA;
T_i – hours of using peak power of the *i*-th transformer, h;
$cos\varphi_i$ – power factor of the *i*-th transformer;
r_{ij}– equivalent resistance of network for the *i*-th transformer, Ohm;
E – some constant value;
$F(k_i)$, $G(k_i)$, – some linear function of k_i.

The solution of system (3) allows to calculate the exact values of the optimal load factor for each transformer.

Developed mathematical model was used for optimization of real electrical network, consisting of 5 transformers. The results and comparison of two way of optimal loading are shown in table 1.

Table 1 – Results and comparison of two ways of optimal loading

Indicators	Optimal load of equivalent network	Optimal load of single transformers
Load energy losses in lines, kWh(%)	9,15(0,53)	9,17(0,52)
Load energy losses in transformers, kWh(%)	22,97(1,33)	23,98(1,36)
Non-load energy losses, kWh(%)	28,84(1,67)	28,93(1,64)
Total energy losses, kWh(%)	61,14(3,54)	62,08(3,53)
Quantity of energy, transmitted to the network, kWh	1727,07	1759,45
Relativity cost of energy transmission $/kWh	2,311	2,303

Table 1 shows, that difference between total energy losses for two ways of optimal loading achievement is not significant. This result allows to use simplified calculations and analysis based on the equivalent networks for real networks.

Conclusions.

1. The authors developed algorithmic method to determine optimal load factors for transformers of distributive electrical networks 6-10 kV.
2. In order to rapidly identify "hot spots" of losses in real distributive networks, it is possible to carry out calculations and analysis based on networks equivalent to original.
3. Calculation of the real electrical networks with optimal load factors allow to determine the economically justified levels of electric energy losses and use them for the development of corrective actions.

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