20th International Conference
ENGINEERING MECHANICS 2014
Svratka, Czech Republic, 12 – 15 May 2014

MINIMISING OF THE OPERATION COSTS OF POWER TRANSFORMERS

D. Perczyński[*], P. Kolber[**], S. Wawrzyniak[***]

Abstract: *The paper demonstrates the problem of profitability of 15/0.4 kV transformers replacement. The transformers work with a small coefficient of peak loads on the units with a lower power rating. The discussion includes fixed and variable costs of the transformers and the costs of their replacement under operating conditions.*

Keywords: Power transformer, Operating costs, Peak load coefficient.

1. Introduction

Power distribution networks are an important part of power system. The networks are characterised by a large number of network devices and receiving nodes. They are time-varying complex dynamic systems. The way of distribution networks operation significantly affects the quality of the power system operation. This is due to their significant participation in fixed assets system, high labour consumption of operating procedures as well as the decisive influence on the efficiency and reliability of electricity supply. They are also the cause of most of losses in the power system.

MV/LV (middle voltage / low voltage) transformers are the important component of power distribution networks. This is due to a significant number of these network elements operating in the public power system.

MV/LV transformers, unlike other basic components of power distribution networks, are easily replaceable and their durability does not change in the result of replacement. Even this feature indicates that they might be adjusted more often to the current load. Operating costs of replaced the transformer depend on peak load. The costs consist of: an amortization cost, costs of idle state loses, load costs, and cost of transformer replacement.

Considering that the economic losses caused by inappropriate use of MV/LV transformers can be significant, the proper selection of transformers becomes a major economic problem. Therefore, examine this issue theoretically as well as lay the foundations to develop practical guidelines of cost-effectiveness of transformer (with a low coefficient of peak power use) replacement can result in significant economic benefits.

2. Costs of Transformer Operating

Changes in the costs of energy transformation of one transformer, depending on the value of its peak load (S_s), are parabola. In diagram of changes in the costs of energy transformation of transformers with different nominal power rating, the parabolas intersect at the point that designates the so-called limit load S_g. Under that load, the annual costs of energy transformation of transformer with a lower power rating are lower than the annual costs of energy transformation of transformer with a higher power rating (Fig. 1.)

[*] Assist. Prof. Daniel Perczyński, PhD.: Institute of Transport and Machine Operation, University of Technology and Life Sciences, Kaliskiego 7/2.3; 85 789, Bydgoszcz; Poland, daniel.perczynski@utp.edu.pl

[**] Assist. Prof. Piotr Kolber, PhD.: Institute of Transport and Machine Operation, University of Technology and Life Sciences, Kaliskiego 7/2.3; 85 789, Bydgoszcz; Poland, piotr.kolber@utp.edu.pl

[***] Assist. Prof. Sylwester Wawrzyniak, PhD.: Institute of Transport and Machine Operation, University of Technology and Life Sciences, Kaliskiego 7/2.3; 85 789, Bydgoszcz; Poland, sylwester.wawrzyniak@utp.edu.pl

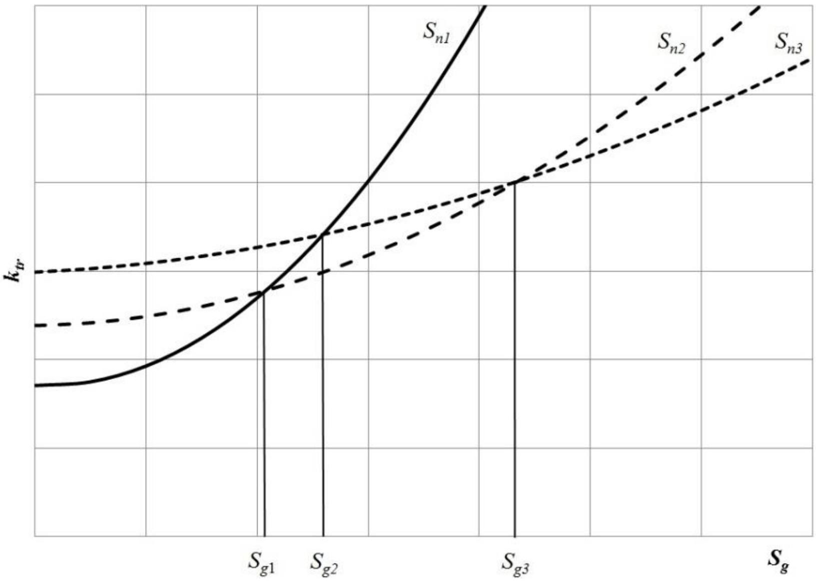

Fig. 1: The costs of energy transformation (k_{tr}) depending on peak load for transformers with power rating $S_{n1} < S_{n2} < S_{n3}$.

Total annual costs of transformation can be presented by the following formula (Niewiedział et al., 1998):

$$K_r = K_e^{st} + K_e^{zm}, \tag{1}$$

whereas annual fixed operating cost of transformer can be calculated from the following equation (Konstanciak, 2000):

$$K_e^{st} = K_n \cdot r_{et} \tag{2}$$

where:

r_{et} – coefficient of fixed operating costs:

$$r_{et} = r_{remt} + r_{ut} + r_{ost} \tag{3}$$

r_{remt} – share of renovation costs in total investment outlays,

r_{ut} – share of maintenance costs in total investment outlays,

r_{os} – share of personnel costs in total investment outlays.

Components of operating variable costs K_e^{zm} show the following equation (Marzecki, J., 1996):

$$K_e^{zm} = \left(\Delta P_j + k_e Q_o\right) T_p c_{\Delta A} + \left(\Delta P_{Cu} + k_e \cdot Q_{obc}\right) \tau \cdot c_{\Delta A} \left(\frac{S_s}{S_n}\right)^2 \tag{4}$$

where:

ΔP_j – nominal power rating losses in the idle state of transformer expressed in [kW],
ΔP_{Cu} – nominal load losses of transformer expressed in [kW],
Q_o – reactive power consumed by transformer at idling operation expressed in [kvar],
Q_{obc} – reactive power losses of transformer at nominal load expressed in [kvar],
k_e – the energy equivalent of reactive power expressed in [kW/kvar],
T_p – annual working time of transformer expressed in [h/year],
τ – annual calculated duration of the maximum loss expressed in [h/ year],
S_s – annual peak load of transformer expressed in [kV·A],
S_n – nominal power of transformer expressed in [kV·A],
$c_{\Delta A}$ – unit cost of energy to cover losses expressed in [PLN/kWh].

Power network should be considered, except in special cases, as an object of unlimited operating time that adapts to the load increment. The basic value of output for planning work of transformers in power stations is the value and increase in peak load as a function of time. With an adoption of exponential growth model of station peak load, the coefficient *k(t)* takes the form:

$$k(t) = \left(1 + \frac{\alpha_{\%}}{100}\right)^t = (1 + \alpha_w)^t \tag{5}$$

where:

α_w – annual relative increase in transformer load expressed in [1/year],

T – subsequent years of transformer operation.

For operating transformer, total annual costs amount in each year:

$$K_r(t) = K_n \cdot r_{et} + (\Delta P_j + k_e Q_o)T_p \cdot c_{\Delta A} + (\Delta P_{Cu} + k_e Q_{obc}) \cdot \tau \cdot c_{\Delta A} \left(\frac{k(t) S_{so}}{S_n}\right)^2 \tag{6}$$

where:

S_{so} – peak load of transformer in the year of replacement to a different unit.

The equation (6) can be written as:

$$K_r(t) = K_n \cdot r_{et} + (\Delta P_j + k_e Q_o)T_p \cdot c_{\Delta A} + (\Delta P_{Cu} + k_e Q_{obc}) \cdot \tau \cdot c_{\Delta A} \cdot \beta_s^2 \cdot k^2(t) \tag{7}$$

where:

β_s – load factor of currently operating transformer during peak load in the year of replacement.

Costs in the electrical power engineering are usually calculated as annual costs for one year which is a basic accounting period. When considering longer periods, the total costs are the sum of discounted costs for subsequent years of accounting period. Summing the costs depends only on two factors of the cost equation: the inverse of the discount rate and relation of squared coefficient of the load growth over the discount rate. Formulas containing these factors with an assumption of exponential model of peak load growth, take the form:

$$D = \sum_{t=1}^{t=T} \frac{1}{q^t} = \frac{q^T - 1}{q^T (q-1)}, \quad E = \sum_{t=1}^{t=T} \frac{k^{2t}}{q^t} = \frac{k^2 (k^{2T} - q^T)}{q^T (k^2 - q)} \tag{8}$$

where:

$q = 1 + p$ - discounting factor.

After considering the above data, the equation describing annual costs of transformer operation in the station takes the form:

$$K_r = K_n \cdot r_{et} + (\Delta P_j + k_e Q_o)T_p \cdot c_{\Delta A} \sum_{t=1}^{t=T} \frac{1}{q^t} + (\Delta P_{Cu} + k_e Q_{obc}) \cdot \tau \cdot c_{\Delta A} \cdot \beta_s^2 \cdot \sum_{t=1}^{t=T} \frac{k^{2t}}{q^t} \tag{9}$$

The period of transformer operation at the station (*T*) is determined by economic criteria while maintaining the technical condition. If for the condition for the maximum load factor of the transformer in the final year of operation at the station accept β_{sk}, then the period of operation *T* is a result of the following relation:

$$T \le \frac{\ln(1 + \beta_{sk} - \beta_s)}{\ln(1 + \alpha_w)} \tag{10}$$

By entering to the equation (7) index 1 for currently operating transformer and index 2 for replaced transformer (smaller that replaces the existing one) and considering the relation (8), the following equation has been obtained:

$$K_{r1} = K_{n1} \cdot r_{et} + (\Delta P_{j1} + k_e Q_{o1})T_p \cdot c_{\Delta A} \cdot D_1 + (\Delta P_{Cu1} + k_e Q_{obc1}) \cdot \tau \cdot c_{\Delta A} \cdot \beta_{s1}^2 \cdot E_1 \tag{11}$$

$$K_{r2} = K_{n2} \cdot r_{et} + \left(\Delta P_{j2} + k_e Q_{o2}\right) T_p \cdot c_{\Delta A} \cdot D_2 + \left(\Delta P_{Cu2} + k_e Q_{obc2}\right) \cdot \tau \cdot c_{\Delta A} \cdot \beta_{s2}^2 \cdot E_2 + K_W \qquad (12)$$

where:

K_w – cost of transformer replacement.

Considering described values of equivalent annual costs of the transformer currently operating at the station and its replacement, the form of criterion functional is defined as:

$$F = K_{r1} - K_{r2} \qquad (13)$$

The dependence of sample values of F functional of replacement transformer power rating on replaced the transformer data: β_{s1} = 0.2, K_w = 1200 PLN, S_{so} = 50 kVA (S_{n1} = 250 kVA), α_w = 0.03, β_{sk} = 1, τ = 2500 h is shown in Fig. 2.

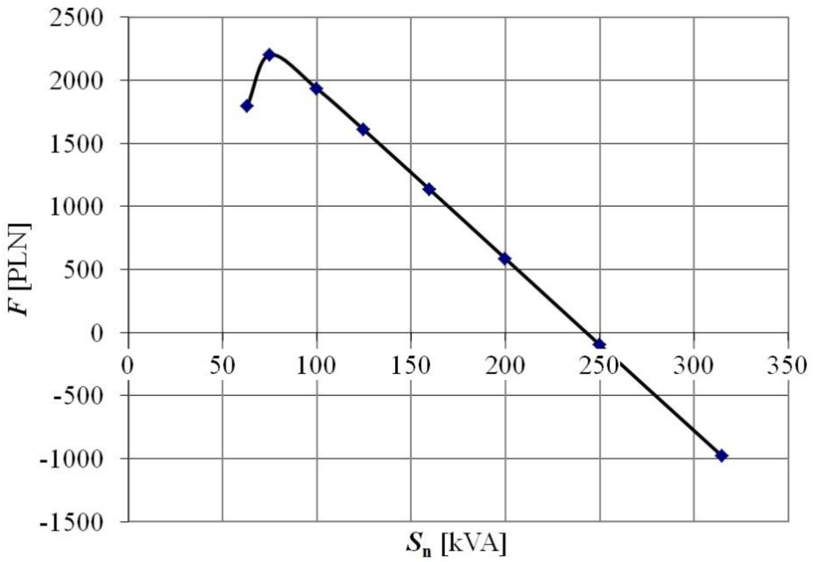

Fig. 2: The dependence of F functional values on transformer power rating.

3. Conclusions

Analysis of obtained results shows that significant number of power transformers operate with low coefficient of peak load. This situation affects the significant economic losses. Determination of the actual costs level of transformers MV/LV operating in the current method of accounting is very difficult. The existing statistics do not provide a precise registration cost components. In subject references (Konstanciak, 2000) there are very different values of constant operating costs coefficients r_c (from 7 to 4.9). Made an attempt to determine particular constant operating costs of Distribution Company shown that coefficient r_c is about 5% of the investment value for analyzed transformer.

The analysis shows that it is profitable to replace a transformer on a one with a lower power rating (in case of underload of currently operating transformer) and the optimum value of the peak load coefficient of replaced the transformer is a function of many variables and is in the range 0.8 – 0.92.

References

Marzecki, J. (1996) Urban Power Networks. Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa (in Polish).

Konstanciak, M. (2000) Economic use if transformers – minimisation of transformation costs. Wydawnictwo Polskie Towarzystwo Przesyłu i Rozdziału Energii Elektrycznej, Poznań (in Polish).

Niewiedział, E., Niewiedział, R. (1998) Analysis of effectiveness of the use of selected technical solutions distribution network MV and LV. Zeszyty Naukowe Politechniki Poznańskiej, Poznań, pp. 67-85 (in Polish).