Jerzy Szkutnik, Anna Gawlak

Dynamic Efficiency of Energy Distribution over Power Networks

Abstract

This paper describes the impact of modern solutions towards network infrastructure on the efficiency of energy distribution in distribution networks. These components included high-temperature wires and SUPERTRAFO transformers. Based on the newest version of author’s software STRATY′2008, extensive analyses of the profitability of these type of solutions in distribution companies have been conducted. The final result was achieved on the basis of the ENE coefficient (Extended Network Efficiency), which enabled complex evaluation of the proposed solutions.

INTRODUCTION

The word „losses” has two meanings i.e. losses in the financial and technical sense. Financial losses can be divided into two types: losses within the norms and losses exceeding the norms. These two categories are differently treated in economic analyses. Losses within the norms are included in operational expenses, while losses exceeding the norms constitute real losses that the enterprise incurs [2,3,4,12]. As technical losses has financial character, it is advisable to divide them into categories like in economics. In real networks, there is also another type of losses, so called trade losses. These are losses connected with the sale of energy, although they can also refer to the purchase of energy. They are not technical losses, but have financial character, so they should also be split into appropriate categories. Different categories of losses shall be analysed separately, because problems connected with them are different.

There are three types of technical losses in the network elements:

- real losses i.e. losses that are incurred in the network,
- justifies losses i.e. losses that can be achieved in the network based on its current condition,
- optimal losses i.e. losses that should be incurred based on the current operational costs.

The latter type of losses cannot be treated in the categories of losses within the norms or exceeding the norms, because they are connected with investments. It should be mentioned here that according to the sample analyses, optimal losses, especially in the medium voltage networks, are higher than calculated. This is a result of the high costs of construction of 110kV and medium voltage stations in proportion to the costs of energy or even variable costs of construction of lines. In low voltage network, results are different. It can happen that the network is overinvested. It results from the decreasing load. So, there are two categories left i.e. real losses and justified losses. The term ‘justified losses’ was introduced in the analysis of losses in 70s. It was assumed then that if there are energy boards that can incur a certain level of losses, other energy boards can also achieve that level. However, one cannot take one energy board that has the best result in one type of losses as a point of reference, because such single result can be a coincidence. So, we took 11 energy boards (1/3 of all) that incurred the lowest level of losses and calculated the average coefficients that have impact on particular types of losses. Lets take asymmetry in low voltage network as an example. The average coefficient of asymmetry of voltage falls in best companies equals 0,25. In a similar way we calculated the average values for coefficients of idealization of network. Only netting of passive power in low and medium voltage transformers was treated differently – there is no point not to net the losses. Full netting leads to the increased losses in low voltage capacitors, but there is higher gain on load losses in medium voltage network. Justified losses can be treated as losses within the norms, while the difference between real losses and justified losses as losses exceeding the norms. Due to the fact that at present there are no calculations of losses for all distribution companies, one can base only on available data i.e. approx. 20 companies. This is however sufficient to draw conclusions. Losses exceeding the norms are over 14% higher than losses within the norms for low voltage network and by 12% higher for medium voltage network –13,25% on average. This is not much, but can be estimated at PLN 2,5 million for an average distribution company. In order to give more insight on this issue, we chose two distribution companies at random and presented their losses for the period of the last 5 years. Figure 1 depicts losses within the norms (justified) and losses exceeding the norms (unjustified).

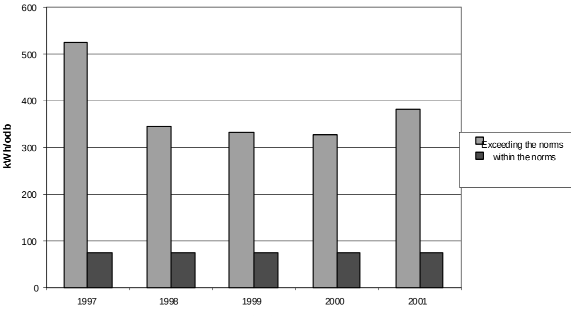


Fig.1. Losses within the norms and exceeding the norms in low and medium voltage networks for a chosen distribution company

High voltage network was excluded from analysis. This network is governed by other rules and any general conclusions cannot be applied to this type of network. One difference results from the fact that decreasing losses in lower voltage networks has some impact on load losses in 110 kV network. However, load losses in 110 kV network have the highest share in overall losses in distribution networks. So, analysis of functioning of 110 kV network can lead to significant benefits. The situation is more complex in case of trade losses. They can be divided into two subgroups: so called systematic losses, commonly existing and losses of illegal consumption. There is also a third category of losses, so called registration losses that result from delays and mistakes in collections or registration of energy consumption. They are however not real losses as well as are insignificant in annual analysis. The are more intensive only in monthly settlements. Consequently, they can be excluded from the analysis.

Systematic losses are easy to interpret. They result mainly from the operational threshold of energy meters. Meters must have such a threshold. They cannot operate without significant cause. This means that there is consumption, which is below that threshold. These are various LEDs, devices of very low power, transformers (e.g. bells), which in stand-by mode consume very little energy. If they operate in the same time as larger devices, their power is summed up with that of larger devices. If they operate separately, their consumption is below the meters' threshold. It can be assumed that systematic losses are a part of losses within the norms. They amount to approx. 75 kWh/receiver per year. This data is not very reliable as they come from research conducted in 70s and 80s. Such research is very expensive and time consuming and one cannot assume that it will be repeated in the near future. However it is assumed that there haven't been significant changes since then. Some argue that meters are more precise, but on the other hand there are many consumptions with little power. Another type of losses that should be analysed are losses of illegal consumption. This issue is more complicated. On one hand, it is obvious that such losses should not exist, but on the other hand it very hard to prevent from these losses and they cannot be eliminated in a short period of time. From the realistic point of view, one can assume that e.g. losses of illegal consumption in the amount equal to systematic losses can be treated as losses within norms, which means that losses within norms were 150 kWh/receiver per year. The rest would be losses exceeding the norms

In summary, justified technical losses and doubled value of trade losses can be treated as losses within the norms, the rest as losses exceeding the norms. The presented analysis of losses is possible based on the last version of the author's software STRATY`2008, which has a broad set of analytical tools for calculation of efficiency of energy distribution in the networks [7,12]. This software was used also for calculations, which were described in more detail in the next sections.

I. NEW GENERATION WIRES

The need of distribution of more and more electrical energy in conjunction with difficulties in obtaining approvals for construction of new lines forces distribution companies to search for ways of increasing the distribution capacity of existing networks. One of the solutions is the increased temperature of wires, which in case of AFL wires operating in +40°C is connected with expensive necessity of making pylons higher and/or strengthening pylons for acceptance of the temperature of +60°C or +80°C – the highest acceptable temperature of AFL wires. In recent years, there was increased use of HTLS wires (High Temperature Low Sag) that operate in max. temperature as high as +250°C. Since 1984, also in Europe high temperature wires have been installed, which proves efficiency of this development. In this article, the authors present some technologies of HTLS wires with special emphasis on ACCC/TW as the best available technology for wires of low sag, which gives the highest increase of line capacity with the lowest costs of installation and operation.

The ACCC/TW wire is very close to ideal wire, because among all wires of low sag, it generates the lowest level of losses, operating with increased temperature and operating in the same temperature as earlier mentioned AFL wire, it reduces losses by 25% [5] compared to AFL wire. This means that due to lower losses, after 1 – 3 years of operation, the ACCC/TW wire is paid off. Moreover, it is the only wire among HTLS wires that due to features of its composite core has almost flat characteristics of the sag in relation to temperature, which means that after exceeding the so called "knee point", the increase of temperature leads to very small increase of the sag. This enables to take full advantage of its operation in high temperatures, whereas other HTLS wires are limited in this respect.

The ACCC/TW wire – the aluminium wire and composite core takes advantage of the aluminium 1350-O and composite core of carbon and glass in polymeric resin. (Fig. 2). Such composition enables operation of the wire in the temperatures up to 200 ^{o}C.

The advantages of ACCC/TW wires are:

- long spans = less pylons, less problems with construction of new lines, lower environmental burden,
- smaller pylons,
- the lowest resistance among all HTLS wires,
- the highest endurance among all HTLS wires,
- very low sag in high temperature,
- resistant to oscillation,
- resistant to ice load,
- the lowest level of release,
- don't include aluminium alloys, but pure aluminium (99,5%).

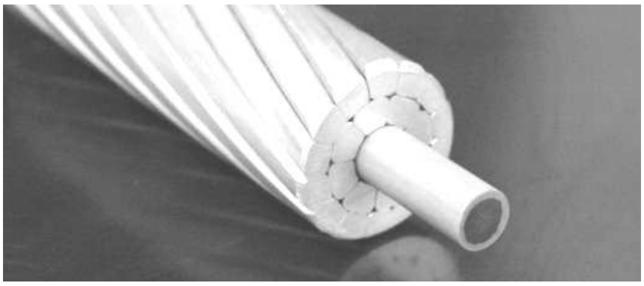


Fig. 2. ACCC/TW wire [5]

II. EFFICIENCY ANALYSES

Nowadays produced transformers can be extremely effective (in 99%), but this parameter depends mainly on the load. Losses in the transformers' core exist all the time, from the activation of the device till its turning off and practically don't depend on the transformers' load. The efficiency of transformer in a conventional way is defined as active power P_2 released by the transformer divided by active power P_1 absorbed by this device (i.e. the sum of P_2 and standby and load losses)

$$\eta = \frac{P_2}{P_2 + \Delta P_j + \Delta P_{obc}}\%, \qquad (1)$$

where: P_2 – active power released by the transformer, kW, ΔP_j – standby losses, kW, ΔP_{obc} – load losses, kW.

As you can see from the formula 1, increased efficiency is made through reduction of unit loss coefficients in transformers and in case of analysis of the whole distribution network, losses in lines.

The investment activities aimed at assuring the highest efficiency of energy distribution shall be based on economic fundamentals. In the following sections of the article, the analysis was limited to one tool i.e. payback period. The payback period is the time needed for cash flows to cover the investments.

$$\text{payback period} = \frac{\text{cost of a new transformer}}{\text{annual profit}} \qquad (2)$$

Assuming the cost of a new transformer ΔK_{ST} is the cost of station resulting from the difference between „super" and „classic" transformer and annual profit as annual inflows ΔW_r resulting from decreased standby and load losses in the transformer, we get the payback period as the time needed for cash flows from investments to cover the investments outlays for modern (more expensive) technology:

$$O_{zw} = \frac{\Delta K_{ST}}{\Delta W_r}, \tag{3}$$

$$\Delta K_{ST} = K_{STK} \cdot \left(K_1 - 1\right), \tag{4}$$

$$\Delta W_r = C_{je} \cdot K_3 \cdot \delta\Delta E_{Tr}, \tag{5}$$

where: O_{ZW} - payback period in years, ΔK_{ST} - cost of additional transformer (station), K_{STK} - cost of classic transformer (station), K_1 – number of times, the cost of „SUPER" transformer exceeds the cost of „CLASSIC" one, ΔW_r - annual inflows, C_{je} - unit energy price, K_3 – energy price index, $\delta\Delta E_{Tr}$ - difference between losses incurred by classic and SUPERTRAFO transformer.

The difference $\delta\Delta E_{Tr}$ is defined by the following formula:

$$\delta\Delta E_{Tr} = \left(\Delta P_{FeN"K"} - \Delta P_{FeN"S"}\right) \cdot T_r \cdot \left(\frac{U_r}{U_N}\right)^2 + \\ + \left(\Delta P_{CuN"K"} - \Delta P_{CuN"S"}\right) \cdot \beta^2 k_T \frac{1}{3}\left(2t_s^2 + t_s\right) \cdot \\ \cdot T_r \left(\frac{U_s \cos\varphi_s}{U_r \cos\varphi_r}\right)^2 \cdot p_R \tag{6}$$

where: $\Delta P_{FeN"S"}$ and $\Delta P_{CuN\ "S"}$ -standby and load losses of „super" transformer, $\Delta P_{FeN"K"}$ and $\Delta P_{CuN"K"}$ - standby and load losses of „classic" transformer, β_s – transformer load coefficient, T_r – time, during which the power P flows through an element, t_s – relative time of the peak load, k_T – coefficient dependent on transformer load, p_R corrective coefficient taking into account changes of resistance of windings according to change of temperature, U_r – average annual voltage on transformer clamps, U_N indicative voltage of transformer, U_s – voltage during peak load, U_o – voltage during trough load.

`The payback period for a single transformer can be described by the following formula:

$$O_{zw} = \frac{K_{STK} \cdot \left(K_1 - 1\right)}{C_{je} \cdot K_3 \cdot \delta\Delta E_{Tr}} \tag{7}$$

The formula (7) includes just the difference between classic and SUPERTRAFO transformers, which is based on statistical analysis.

In order to make the analysis more complex, one should include in calculations also the changes in the superior network i.e. network that supplies the analysed transformers. This is described by the formula (8).

$$O_{zwe} = \frac{K_{STK} \cdot \left(K_1 - 1\right)}{C_{je} \cdot K_3 \cdot \left(\delta\Delta E_{Tr} + \delta\Delta E_{S1} + \delta\Delta E_{S2}\right)}. \tag{8}$$

In this case the decreased losses in the network resulting from two reasons were included: lower flows of power due to more economical transformers ($\delta\Delta E_{S1}$) and due to the usage of wires of the new generation in the 110 kV line ($\delta\Delta E_{S2}$). Such analysis can be described as a dynamic one.

There are two coefficients for efficiency analysis:

$$ENE_T = \frac{O_{zw}}{O_{zwe}}, \tag{9}$$

$$ENE_{\delta\Delta E} = \frac{\left(\delta\Delta E_{Tr} + \delta\Delta E_{S1} + \delta\Delta E_{S2}\right)}{\delta\Delta E_{Tr}}, \tag{10}$$

where: ENE_T - timely increase of efficiency, $ENE_{\delta\Delta E}$ - network increase of efficiency.

Both coefficients analyse the operation of network elements and the network in a way that they can be included in the group of coefficients that enable dynamic analysis of efficiency of energy distribution.

Fig. 3 and Fig. 4 depict the impact of the basic k parameters (K_1 and K_3) on the payback period based on formulas (7) and (8).

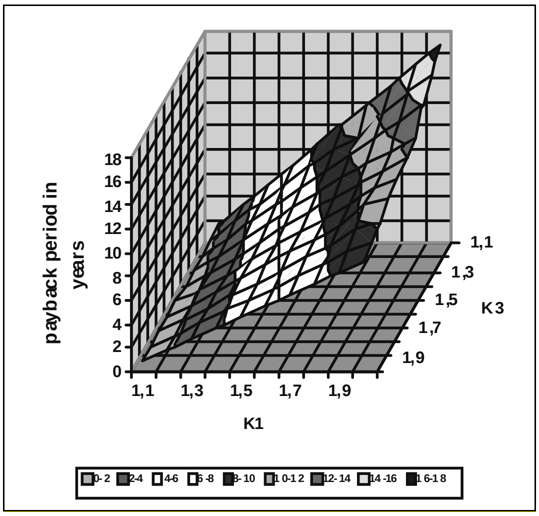


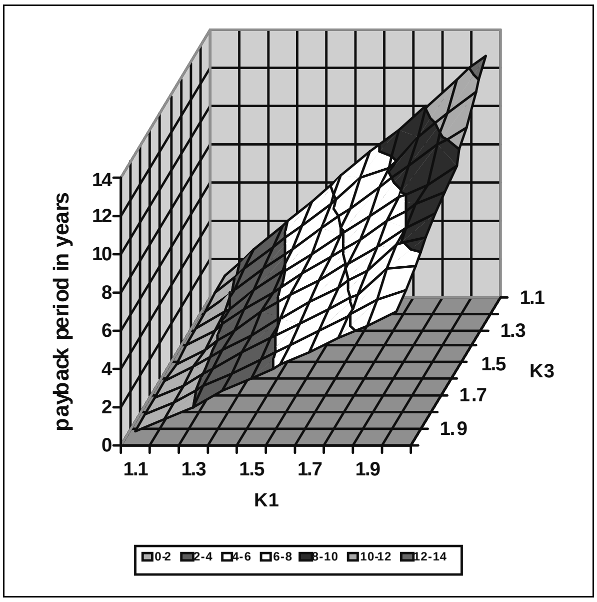
Fig. 3. Payback period O_{zw} as a function of K_1 and K_3

Additionally the average values of ENE coefficients were calculated. They amount to:

ENE_T = 1,36,

$ENE_{\delta\Delta E}$ = 1,32.

Such coefficients prove additional benefits resulting from the usage of effective solutions in the network. They shorten the payback period by approx. 36% on one hand and increase the efficiency of energy distribution by approx. 30% on the other. These values shall be treated as targeted, dependent on the level of density of investments aimed at increasing efficiency. It should also be noticed that payback periods are quite short. According to static analysis, they range from 3,3 to 8,5 years depending on the relation between costs of super and classic transformer. After inclusion of additional effects of superior network (dynamic analysis), payback periods range from 2,5 to 6,5 years. They decrease substantially in both cases when increase of energy prices by 30% is assumed.



III. **Fig. 4.** Payback period O_{zwe} as a function of K_1 and K_3

The above mentioned coefficients constitute justified recommendation for more common usage of the proposed solutions by distribution companies.

III. SUMMARY

The presented ways of increasing efficiency of energy distribution in the networks constitute an example of searching new solutions for existing problems. The defined coefficients may be used as additions to economic analyses of efficiency of new developments. This research shall be continued and broaden from one level of the network, as described in this article, to the whole network, both low, medium and 110kV voltage.

REFERENCES

[1] Jahnatek L., Szkutnik J.: The Model of Efficiency Management in the Distribution Utilities Development of Enterprises. Energy and Environment in Knowledge Based Economy, edited by Tomasz Nitkiewicz & Ralph Lescroart, Haute Ecole "Blaise Pascal, Arlon 2008, Library number: depot legal: D/2008/9727/6, Edited in Belgium.

[2] Kolcun M., Bena L., Mecszaros A., Rusnak J.: Riesenie problemov v riadeni prevadzky elektrizacnych Gustav s vyuzitim FACTS zariadeni. In ELEKTROENERGETIKA Symposium Proceedings, Stara Lesna, 2005, Kosice, Katedra Electroenergetiky, FEI TU v Kosicach, 2005.

[3] Sokolik W.A: Nowoczesny sposób na szybkie zwiększenie zdolności przesyłowych linii napowietrznych za pomocą przewodów o małych zwisach. V Konferencja Szkoleniowo-Techniczna NOE 2008 Nowoczena Energetyka. Politechnika Lubelska, Nałęczów 3-5.12.2008 r.

[4] Szkutnik J.: Benchmarking in the Development of Enterprises. Energy and Environment in Knowledge Based Economy, edited by Tomasz Nitkiewicz & Ralph Lescroart, Haute Ecole "Blaise Pascal" , Arlon 2008,, Library number: depot legal: D/2008/9727/6, Edited in Belgium.

[5] Szkutnik J.: Efficiency and Quality in Management of Energy Distribution. The Challenges for Reconversion Innovation – Sustainability-knowledge Management. Edited by Piotr Pachura, Institut Superieur Industriel Pierrard HEC du Luxembourg VIRTON, Belgium 2006, Depol legal: D/2006/9727/3.

[6] Szkutnik J.: Extend Network Efficiency Indicator as the Modern Tool in Energy Distribution Europe. The 2nd International Scientific Symposium, ELEKTROENERGETIKA EE`2003, Technical University of Kosice September 16-18, 2003, High Tatras-Stara Lesna, Slovak Republic.

[7] Szkutnik J.: The Energy Efficiency as the Necessary Element of the Planning in the Sector of the Electrical Energy. Proceedings of the 9th International Scientific Conference ELECTRIC POWER ENGINEERING 2008, EPE`2008, May 13-15 2008, Brno. Czech Republic.

ADDRESSES OF AUTHORS

Jerzy Szkutnik, Częstochowa University of Technology, Faculty of Electrical Engineering, ul. Armii Krajowej 17, 42-200 Częstochowa, Poland
szkutnik@el.pcz.czest.pl

Anna Gawlak, Częstochowa University of Technology, Faculty of Electrical Engineering, ul. Armii Krajowej 17, 42-200 Częstochowa, Poland
gaqwlak@el.pcz.czest.pl