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PROGRAMMING OF RURAL POWER NETWORKS DEVELOPMENT PART II. DRAFT GUIDELINES FOR THE LOCAL PLAN OF ENERGY SUPPLY

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Summary. In order to draw up draft guidelines to the plan of energy supply for Zabierzów Commune, as a form of implementing the suggested concept for network development, local needs concerning the modernisation and development of rural power networks were determined. The calculations and simulations have been carried out for two development scenarios for the commune, depending on the adopted annual increase in the network's peak load.

Key words: power networks, development of rural networks, local power planning

INTRODUCTION

The own tasks of the commune include, among others, local supply with electric energy. The provisions of the Energy Law [Dz.U. z 1997 r. nr 54] associate the tasks of the commune, as resulting from the Local Authority Act [Dz.U. nr 13 z 1996 r.], with the requirements of the energy policy and country's energy security [Polish Energy Policy until 2025] and environmental protection [Dz.U. nr 49 z 1994 r.] and obligate them to draw up draft guidelines to plans, including the plans for energy supply. Such documents should include local needs, concerning the development of power infrastructure, taking into account the binding quality requirements, as well as the needs and expectations of consumers. The complexity of the issue of the planning of power infrastructure development and inaccuracies in the binding legal acts concerning the deadline for the preparation of the afore-mentioned planning documents led to the situation that only around 28% of Polish communes were in possession of such planning documents, as of the end of 2007 [Walski 2008]. Therefore, the majority of the communes are unable to shape their own energy management in an organised and optimum manner, given their specific local conditions [Ajersz 2005; Butkowski, Maszkiewicz-Kobacka 2005; Planowanie energetyczne… 2002]].

The objective of this work was to determine local needs, concerning the development of rural low-voltage power networks, as required for the needs of the drawing up of draft guidelines to the plan for energy supply of a selected commune.

MATERIAL AND METHODS

The objective of the work was illustrated with an example of Zabierzów Commune, which is located in close vicinity of the City of Kraków. It is one of the biggest communes in the province of Małopolska. It occupies the area of 99.6km2, which is 8.1% of the county of Kraków. It is dominated by cultivated land (65%) and forests (14%). The commune comprises 23 villages, inhabited by over 22,000 people. In terms of population density, it is the third commune out of the total of 17 communes in the county of Kraków.

Based on the concept for the development of power infrastructure presented in Part I of this work [Trojanowska, Nęcka 2010], it was possible to estimate local needs related to the modernisation and development of rural low-voltage distribution networks, which supply electric energy to the population of Zabierzów Commune, taking into account proper quantity and required quality parameters. The calculations have been made for two scenarios for rural area development, for which the time horizon is 2020. The scenario approach enables the determining of the field of potential directions of development, by the continuing or changing of certain trends, observed in the past.

Scenario I is based on the assumption that the trend in changes of the annual rate of the increase in consumer demand for electric energy and the annual peak load of the network, within the analysed area, between the year 1993 and 2007, will remain intact, i.e. will amount to 3% a year, till 2020.

Scenario II expects a lower, 1% increase in the rate of the annual consumption of energy and peak load, as we have observed a tendency to decrease its value in the recent years.

The planning of network development and calculating of costs for the years 2008-2020 was based on fixed prices. Such method is all the more justified, as the proportions between the elements of costs were not subject to significant fluctuations in the recent years and there is much evidence that this tendency will continue.

The required calculations and simulations have been made using a spreadsheet.

RESULTS

Because of the exceeding of the permissible voltage drops as the decisive factor, the development of the LV power networks may consist in the increasing of the number of transformer stations and/or increasing of the cross-section of line conductors. Such solution is possible only provided that the existing lines and transformer stations are in good technical condition.

This work is based on the variants for the network development that are most commonly applied, and consist in [Horak, Popczyk 1995; Kulczycki, Szpyra 1993]:

- building of a new MV/LV transformer station, leaving the LV network virtually intact,
- increasing the cross-section of LV line conductors, by constructing a second line on the existing posts, without altering the arrangement and number of the MV/LV transformer stations,
- increasing the cross-section of LV line conductors, by replacing the conductors with new ones of larger diameter, without altering the arrangement and number of the MV/LV transformer stations.

Prior to the simulation studies of infrastructure development, there was an economic analysis of the alternative variants for the development of low-voltage networks, based on the annual cost method, as it is commonly applied for the economic evaluation of the planned power networks [Kujszczyk 1984; Laudyn 1999; Marzecki 2002, 2005, 2007].

Since power networks are subject to continuous development, it implicates changes in the number of equipment installed in the network, as well as in the power and energy sent through that network. The economic evaluation of the alternative variants for network development was based on the discount calculus [Kujszczyk 2004; Laudyn 1999; Marzecki 1993, 2002, 2005, 2006]. According to this calculus, the current value of the criteria functional F0, i.e. the value of year 0, is equivalent to the value of the functional Ft in year t, calculated based on the following formula:

$$F_t = \sum_{t=1}^{T} \left(\left(K_{il} \cdot (r + r_e) + K_{zmlt} \right) + \left(K_{ist} \cdot (r + r_e) + K_{zmst} \right) \right) \cdot (1 + p)^{-t}, \tag{1}$$

in which p is the rate of discount, usually equivalent to the rate of accumulation allowance. In the case of network modernisation, the symbolic year 0 is the year that precedes the year in which the research is commenced.

The optimum decision (strategy) concerning the development of the analysed network system is the variant for which the sum of discounted investment expenditures and variable costs, related to network use, is the lowest.

The total investment cost for the line of length l can be expressed as:

$$K_{il} = k_{il} \cdot l, \tag{2}$$

where:
k_{il} – unit cost of line construction [thousands of PLN · km-1],
l – length of line [km].

The unit cost of line construction kil is established based on the sum of material costs (conductors, posts, network fittings), costs of labour and costs of equipment operation. The unit cost for other equipment (transformers with workstations, fields in the switchgear, etc.) is equal to the investment cost for each individual element. Therefore, the equation of investment costs for the transformer station is as follows:

$$K_{ist} = K_{irg} + K_{it} + K_{ie} \tag{3}$$

where:
K_{irg} – the total investment cost of the switchgear [thousands of PLN],
K_{it} – the total investment cost of the transformer, incl. fittings [thousands of PLN],
K_{in} – the total investment cost of other equipment [thousands of PLN].

The annual variable costs of power and energy losses of the line for each successive year is presented by the following formula:

$$K_{zmlt} = k_{plt} \cdot \Delta P_{lt} + k_{Elt} \cdot \Delta E_{nlt} \tag{4}$$

where:
ΔP_{lt} – losses in real power of the line in year t [kW],
ΔE_{nlt} – losses in energy of the line in year t [kWh],
k_{plt} – unit cost of power in the line in year t [thousands of PLN ×kW^{-1}],
k_{Elt} – unit cost of energy in the line in year t [thousands of PLN ×kWh^{-1}].

The annual variable costs of power and energy losses in the transformer for each successive year is presented by the following relationship:

$$K_{zmst} = e \cdot k_{pst} \cdot \Delta P_{st} + k_{Est} \cdot \Delta E_{nst} \tag{5}$$

where:
ΔP_t – losses in real power in the transformer in year t [kW],
ΔE_{mt} – losses of energy in the transformer in year t [kWh],
ε – the coefficient of the participation of the ΔP_t losses in the peak load of power network,
k_{pmt} – unit cost for power in the transformer in year t [thousands of PLN $\cdot$ kW^{-1}],
k_{Emt} – unit cost of energy in the transformer in year t [thousands of PLN $\cdot$ kWh^{-1}].

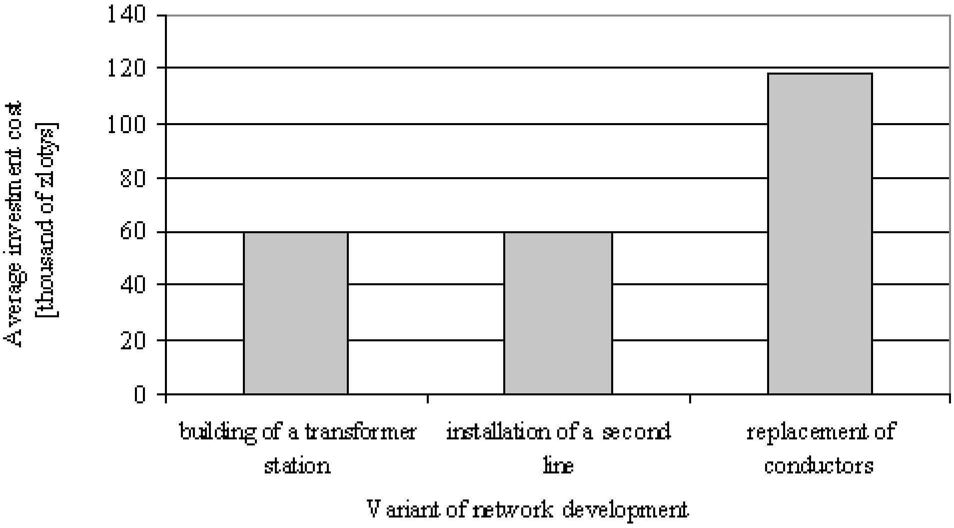

Fig. 1. Average investment expenditures for the variants of network development

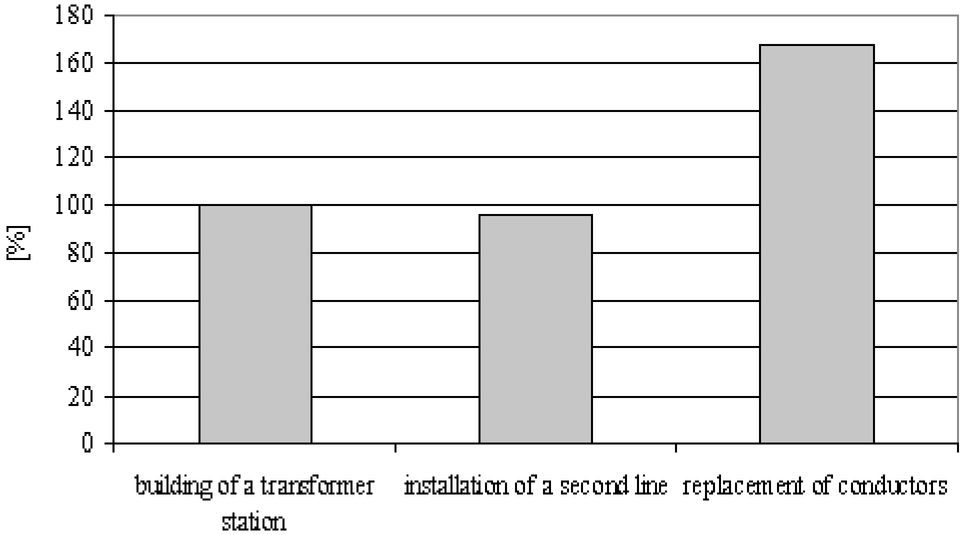

Fig. 2. Comparison of annual discounted costs for the variants of network development

The completed analysis enabled the determining of average investment costs for each individual variant of network development (Fig. 1). It showed that for the 0.08 rate of discount the differences in the annual discounted costs, between the installation of the second line circuit and constructing a transformer station, are small and amount to around 4%, in favour of the first solution (Fig. 2). The modernisation of network by the replacing of conductors results in an almost 70% increase in the annual discounted costs, and requires almost a double increase in the investment expenditures, as compared to other variants. Therefore, further sections of this work were narrowed to the analysing of two alternative variants for network development, i.e. the installation of another line circuit and constructing a transformer station, both considered as economically justifiable.

As the result of the completed analyses for an area representative for the rural areas of the Zabierzów Commune, power with 120 MV/LV transformer stations, it was possible to estimate the needs in the scope of the development of rural power infrastructure for the planned scenarios of development, which would provide the regulatory quality of the supply voltage, by 2020. Those needs, together with the indicators that characterise networks, after the completion of the required investments, have been presented in Table 1.

Table 1. Need in the scope of the development of rural low-voltage power network, within the area of Zabierzów Commune, until 2020, as well as the indicators that characterise potential effects

Quantity	Scenario I	Scenario II
Share of LV circuits that require modernisation [%]	15	5
The required increase in the number of transformer stations - MV/LV [%]	37	12
Average length of a LV circuit in 2020 [m]	532	582
Expenditures on the development of networks [thousands of PLN]	2677	892
Reduction in the costs for power and electric energy losses [%]	21	5

CONCLUSIONS

The completed analyses and simulation studies clearly show that at the current level of supply voltage, within the rural areas of Zabierzów Commune, around 2% of the LV line circuits need to be modernised. By 2020, in order to provide the required quality of power supply, it will be necessary to modernise another 5-15% of lines, depending on the adopted scenario for the annual increase of the network's peak load. The implementation of the adopted scenarios requires investment expenditures between 0.9 and 2.7 million PLN.

The modernisation and development of power networks provides both the improvement in the quality of supply voltage and the reduction of costs for the losses in power and electric energy in lines and transformers in the range between a few and several dozen per cent. The performed calculations have shown that the development of network by the building of new transformer stations is characterised by a greater, around 50% reduction of the costs for losses in power and electric energy, as compared to the modernisation by constructing a second power line. An additional advantage of the developing of power networks by the constructing of new transformer stations is the reduction in circuit lengths, which directly influences the efficiency of the electric shock protection.

The results of calculations and simulations presented in the work may be adopted by the local government of Zabierzów Commune in energy planning as a form of implementing the concept for the development of rural power networks, particularly when preparing draft guidelines to the energy supply plan for the commune.

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PROGRAMOWANIE ROZWOJU WIEJSKICH SIECI ELEKTROENERGETYCZNYCH. CZĘŚĆ II. PROJEKT ZAŁOŻEŃ DO PLANU LOKALNEGO ZAOPATRZENIA W ENERGIĘ

Streszczenie. Wyznaczono lokalne potrzeby w zakresie modernizacji i rozbudowy wiejskich sieci elektroenergetycznych dla potrzeb opracowania projektu założeń do planu zaopatrzenia gminy Zabierzów w energię, jako aplikację zaproponowanej koncepcji rozwoju sieci. Obliczenia i symulacje wykonano dla dwóch scenariuszy rozwojowych gminy, w zależności od przyjętego przyrostu rocznego obciążenia szczytowego sieci.

Słowa kluczowe: sieci elektroenergetyczne, rozwój sieci wiejskich, lokalne planowanie energetyczne