TEKA Kom. Mot. Energ. Roln. – OL PAN, 2010, 10, 484–490

PROGRAMMING OF RURAL POWER NETWORKS DEVELOPMENT
PART I. MODELING OF NETWORKS DEVELOPMENT

Małgorzata Trojanowska, Krzysztof Nęcka

Department of Power Engineering and Agricultural Processes Automation,
Agricultural University of Cracow
Balicka Str. 116B, 30-149 Kraków, Poland
e-mail: malgorzata.trojanowska@ur.krakow.pl; krzysztof.necka@ur.krakow.pl

Summary. This article presents the relationships that characterise the development of rural power networks, which have been described in a manner which enables their practical implementing in the local power planning within the area of Southern Poland. The study also presents a concept for the development of such networks based on the suggested relationships.

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

INTRODUCTION

The building up of loads, changes in the structure of the utilised load points, the increase of the requirements of consumers in the scope of the quality of the electric energy supply, and the ageing of the existing facilities and network equipment implicates the need for the modernisation and development of power networks.

Today, the rural distribution networks in Poland comprise around 206 thousand km of medium-voltage (MV) lines, 254 thousand km of low-voltage (LV) lines and 151 thousand MV/LV transformer stations [Trojanowska 2005]. They transmit electric energy to 14.8 million residents of rural areas, i.e. 40% of the population in Poland, which annually consumes 10182 GWh [Rocznik statystyczny 2009].

More than half of the existing power infrastructure was built as part of the general electrification of rural areas and with very low financial outlays. The majority of the existing infrastructure was built on the basis of the cheapest overhead lines with bare conductors and overhead transformer/pole stations, which are particularly exposed to failures caused by weather conditions [Ocena ... 2005; Niewiedział E., Niewiedział R. 2006, Statystyka elektroenergetyki polskiej 2005; Żmijewski 2006].

The significance of the development of rural power network infrastructure has been confirmed by the provisions of the document of 27th March 2006, title *Program for Electrical Power Engineering*, which consider the building of new transmission lines and the development of distribution networks to be the most important issues of the power sector, which require immediate solutions. Without the thorough modernisation of distribution networks the actual state of the power network infrastructure hinders (in many cases even prevents) further development of rural areas.

The development of network equipment should be based on the expected loads in such a way that it provides proper development of the power network infrastructure, both in the technical and economic aspect. The increase in the surface density of electric energy must implicate changes in the criteria for network development, starting with the mechanical resistance criterion, through voltage and economic criteria and, finally, taking into consideration the criteria for permissible loads [Horak 1997].

The authors of studies concerning the distribution systems for electric energy are looking for the optimum strategies for the development of power networks, i.e. such technical solutions which would simultaneously satisfy the requirements concerning the quality of the supplied electric energy and provide the lowest annual discounted costs of supply [Buriak 2004; Gawlak 2009, Kulczycki, Szpyra 1993; Marzecki 2002, 2005, 2007; Marzecki, Saganek 2007; Niewiedział, Niewiedział 1998]. The development of power networks is related to the introduction of each new network element/facility at the optimum time, particularly a new transformer station or line, as well as change of the parameters of the existing facility, e.g. altering the line section or replacing a transformer.

In previous years the process of optimisation was usually implemented using the standard methods for mathematical programming or various heuristic methods. The most commonly applied methods include linear programming, quadratic programming, non-linear programming, dynamic programming, method of divisions and limitations, discrete optimisation, *Branch and Bound* algorithm [Buriak 2004; Kujszczyk 2004].

Although the classic methods are still universally used, we observe the growing implementation of optimisation techniques, based on artificial intelligence methods. The problems related to the optimisation of the power network development are solved using artificial neural networks, evolutionary algorithms and fuzzy logic [Buriak 2004; Kujszczyk 2004]. We can also come across hybrid solutions that combine various methods of artificial intelligence or combinations of artificial intelligences and classic methods.

The implementation of the mentioned methods for the optimisation of distribution networks does not always lead to any solutions. The final model may be too complex and its solution impossible or too time-consuming. Therefore, it is reasonable to search for simplifications of such methods, in favour of their clarity and easiness of practical adaptation in the process of planning the development of power networks.

The objective of this work was to elaborate the relationships that characterise the development of rural power networks, in a manner which would enable their practical implementation in the local power planning. This study also presents a concept for the development of the networks.

MATERIAL AND METHODS

The objective of the study has been achieved by the authors' own research of typical low-voltage power networks, which supply electric energy to the rural consumers in the region of Małopolska, and the data concerning the technical parameters of those networks obtained from distribution companies. The research consisted in the on-going (24h) measuring and recording of the average, 10-minute loads of real power, using specialised AS-3 microprocessor equipment. The measurements were carried out at representative rural 15/0.4kV transformer stations, which are the source of energy commonly used to supply power for households and farms.

RESULTS

Modernisation and development of power networks is most often carried out as the result of poor quality of supply voltage, particularly due to the exceeding of the permissible ranges of voltage by consumers. The improvement in the quality of supply voltage can be achieved by the increasing of the cross-section of conductors and/or decreasing of the length of power supply circuits for consumers by building new transformer stations.

This article analyses the existing low-voltage power network that provides electric energy supply to rural consumers. Each single MV/LV transformer station which is part of the distribution network as well as the LV lines that are led out from such stations are characterised using the following parameters:

S_n – transformer rated power,

l – length of the line circumference,

R_j – unit resistance of the line,

E_d – 24h consumption of electric energy recorded at the transformer station at the peak load of the system.

We also know the course of a typical, reduced, ordered diagram of consumer loads per one week of a peak load of the electric energy system. In order to satisfy the objective of this study, such diagram (Fig. 1) has been prepared on the basis of the demand for power of rural consumers in the area of Małopolska.

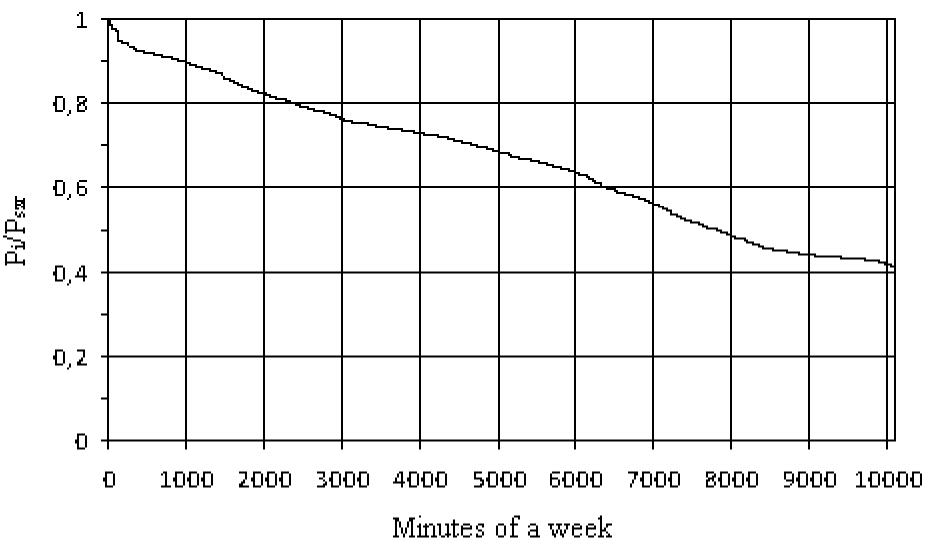

Fig. 1. Reduced, ordered diagram of load for rural consumers, within a week of system peak load

It is assumed that within the analysed time-span the summary length of low-voltage lines is not subject to change, and it is possible to alter the cross-sections of the conductors that comprise such lines and build new MV/LV transformer stations. The load of the network will also be subject to changes, as a result of the changes in the electric energy consumption rate, according to the drawn-up prognosis. As for the cosφ power factor related to the consumers at the peak load of the power system, it will remain at the present level, determined on the basis of the authors'own research, which equals to 0.96.

The peak load of the 15/0.4kV transformer station in year t (P_{szt}) will be determined on the basis of the value of the expected twenty-four hour consumption of electric energy at the daily peak load (E_{dt}) by the consumers supplied through the station, according to the following relationship:

$$P_{szt} = 0{,}069 \cdot E_{dt}, \qquad (1)$$

where: P_{szt} is represented in w kW, and E_{dt} in kWh.

The afore-mentioned relationship was determined according to the analysis of correlation and regression. The calculations showed that 97% of the total annual variability of the peak load of the transformer station P_{szt} can be explained by the linear regression, which signifies a very good fitting of the model (1) to empirical data. Based on the value of the peak load of the MV/LV transformer station, it is possible to determine the peak load for the LV lines that are led out from the station, using the following relationship [Sopyła, Niebrzydowski 1988]:

$$P_{sznt} = \tau_t \, l_{nt}, \qquad (2)$$

$$\tau_t = \frac{P'_{szt}}{\sum_{n=1}^{w} l_{nt}}, \qquad \text{for } t = 1, 2, ..., T, \qquad (3)$$

where:

τ_t – unit load of the LV network in year t [kW×km^{-1}],

P'_{szt} – the annual peak load of the MV/LV transformer station in year t [kW],

P_{sznt} – the annual peak load of the nth circuit of the LV line led out from the transformer station in year t [kW],

l_{nt} – the length of the nth circuit of the LV line led out from the transformer station in year t [km],

w – number of circuits of the LV lines led out from the transformer station [items].

It enables the determining the demand for power in each 10-minute time period of the week, based on the reduced and ordered diagram of loads and the expected annual peak load of the network per one week in the peak load of the power system. The estimated loads enable the calculation of drops in voltages in the lines, according to the formula:

$$\Delta U_{\%} = \frac{100 \cdot P_l \cdot l \cdot R_j \cdot k}{U_N^2}, \qquad (4)$$

where:

$\Delta U_{\%}$ – voltage drop in the line [%],

P_l – real power load of line [W],

l – length of line circumference [km],

R_j – unit resistance of the line [Ω·km^{-1}],

k – correction factor,

U_N – network's rated voltage [V].

The correction factor k, as introduced to the formula for the calculation of voltage drop, takes into consideration the values of voltage drop caused by the difference in peak loads at consumers, the asymmetry of phase load, number of consumers and branches in the line, non-uniformity of power consumed by consumers, non-uniformity in distances between consumers, as well as the level of line capacity utilisation. This level amounts to 0.64 for rural low-voltage distribution networks in Southern Poland and it has been determined based on the authors' research which consisted in the measurement of voltages at the start and end of standard rural network circuits.

With known voltage drops, it is possible to determine the values of supply voltage at consumers. If, in the peak week, one value in the set of the 10-minute average rms values of supply voltage exceeds 15% of the rated voltage, or 5% of the values of the set of the 10-minute average rms values of supply voltage exceed 10% of the rated voltage, it will enable the simulation of the network development. If the analysed circuit is more than 500m long, its development will consist in the construction of a new transformer station. In all other cases, the simulation of the development of the power network infrastructure will consist in the increasing of the cross-section of the feeder cable and constructing of a new transformer station. The criterion for the selection of a solution is the minimization of investment expenditures and maintenance costs.

In the variant for the development of the network by the construction of a new medium- and low-voltage transformer station it is suggested to locate it in the middle of the line's length. The forecast loading of the low-voltage line is divided proportionally, according to length, between the circuit that remains in the existing station and the circuit led out from the newly built station. The rated power of the transformer S_n in the newly built station will be matched according to the expected peak load of the transformer for the last year (T) of the analysed time-period, according to the following relationship:

$$S_n = \frac{P'_{snT}}{0{,}96}, \qquad (5)$$

where:
P'_{snT} – the peak load of the medium- and low-voltage transformer station in year T [kW],
S_n is presented in kVA.

The relationship that characterises the minimum transformer power does not take into consideration the factor that determines its permissible overloading (the value of this factor is specified in the PN-71/E-81000), as manufacturers do not recommend to do so. The value of the minimum transformer power, as calculated according to this relationship (5), is rounded to the nearest standardised value, but not lower than 63 kVA.

As for the required cross-section of the line, it is determined based on the calculated maximum unit resistance of the conductors, according to the formula:

$$R_{jmax} = \frac{\Delta U_{\%dop} \cdot U_N^2}{100 \cdot P_{lT} \cdot l_T \cdot k}, \qquad (6)$$

where:
R_{jmax} – the maximum unit resistance of the line [$\Omega \cdot km^{-1}$],
$\Delta U_{\%dop}$ – the permissible voltage drop in the line [%],
P_{lT} – real power load of the line in year T [W],
l_T – length of line circumference in year T [km],
k – correction factor.

The maximum unit resistance, as calculated based on this relationship (6), is rounded up to the nearest value for cross-section of standardised conductors.

In order to verify the correctness of the established relationships, they were used to simulate the development of rural distribution networks for a small administrative area. The determined needs concerning the building of medium- and low-voltage transformer stations have been compared to the results obtained when using the optimisation calculus. The relative differences in the number of rural medium- and low-voltage transformer stations, as determined on the basis of the suggested relationships and the optimisation calculus, have not exceeded 6%.

CONCLUSIONS

According to this study, the concept for the development of the power network infrastructure, which constitutes the implementation of the determined relationships, is suitable to estimate the needs in the scope of modernisation and development of the rural LV networks in Southern Poland. In consideration of its relatively simple form of calculation, it can be applied by local authorities as early as in the preparation phase of the statutory draft guidelines to the local plans for energy supply.

The established relationships that describe the development of the rural low-voltage networks may be transformed into computer software. The calculations may also be made using a spreadsheet.

REFERENCES

Brożek J., Tylek W. 2006.: Zastosowanie algorytmów ewolucyjnych do optymalizacji promieniowych struktur sieci elektroenergetycznych. Przegląd Elektrotechniczny 9. s. 60–62.

Buriak J. 2004.: Nowoczesne metody planowania rozwoju systemu dystrybucji energii elektrycznej. Przegląd Elektrotechniczny 10. s. 967–970.

Gawlak A. 2009.: Podział środków inwestycyjnych na rozwój sieci rozdzielczych przy zastosowaniu metody taksonomicznej. Przegląd Elektrotechniczny 3. s. 157–160.

Horak J. 1997.: Sieci elektryczne. Część 1. Elementy sieci rozdzielczych. Wydawnictwo Politechniki Częstochowskiej. Częstochowa.

Kulczycki J., Szpyra W. 1993.: Modelowanie rozwoju wiejskich sieci rozdzielczych. Materiały III Sympozjum „Metody matematyczne w elektrotechnice". Zakopane. s. 37–42.

Kujszczyk S. (red.) 2004.: Elektroenergetyczne sieci rozdzielcze. Tom 2. Oficyna Wydawnicza Politechniki Warszawskiej. Warszawa.

Marzecki J. 2002.: Metody ekonomiczne przy badaniu rozwoju sieci elektroenergetycznych. Przegląd Elektrotechniczny 8. s. 245–250.

Marzecki J. 2005.: Analiza ekonomiczna elektroenergetycznych sieci terenowych. Przegląd Elektrotechniczny 4. s. 66–74.

Marzecki J. 2007.: Optymalne struktury i konfiguracje terenowych sieci niskiego i średniego napięcia. Przegląd Elektrotechniczny 7–8. s. 64–67.

Marzecki J., Saganek D. 2007.: Kryteria podejmowania decyzji przy projektowaniu sieci elektroenergetycznych. Wiadomości Elektrotechniczne 7. s. 21–24.

Niewiedział E., Niewiedział 1998.: Analiza opłacalności stosowania wytypowanych rozwiązań technicznych sieci rozdzielczych SN i nN. Zeszyty Naukowe Politechniki Poznańskiej. Elektryka 45. s. 67–85.

Niewiedział E., Niewiedział R.: 2006. Prognozowanie potrzeb rzeczowych w zakresie modernizacji i rozwoju sieci elektroenergetycznych średniego i niskiego napięcia na terenach wiejskich. Przegląd Elektrotechniczny 9. s. 63–65.

Ocena przewidywanych potrzeb rozwojowych i odtworzeniowych sieci elektroenergetycznej średniego i niskiego napięcia na obszarach o małym zagęszczeniu odbiorców. 2005. Materiał źródłowy PTPiREE. Poznań.

Polska Norma PN–71/E–81000. Obciążalność transformatorów o naturalnym obiegu oleju.

Program dla elektroenergetyki. Dokument przyjęty przez Radę Ministrów 28 marca 2006 r. Warszawa.

Rocznik Statystyczny. 2009.GUS.

Sopyła W., Niebrzydowski J. 1988.: Koncepcja modelu rozwoju wiejskich stacji transformatorowych w warunkach niepewności. Materiały Konferencji Naukowo-Technicznej „Racjonalizacja zużycia energii elektrycznej, paliw i materiałów w gospodarce narodowej". s. 155-168.

Statystyka elektroenergetyki polskiej 2005.: Agencja Rynku Energii S.A. Warszawa.

Trojanowska M. 2005.: Analiza statystyczna stanu wiejskich sieci elektroenergetycznych niskiego napięcia w Polsce. Materiały Konferencji Naukowej „Bezpieczeństwo energetyczne". Orieł Rosja. s. 77–83.

Żmijewski K. 2006.: Za 5 lat energetyka zacznie się sypać. [online]. [dostęp 17.01.2008]. Dostępny w Internecie: http://www.cire.pl.

PROGRAMOWANIE ROZWOJU WIEJSKICH SIECI ELEKTROENERGETYCZNYCH CZĘŚĆ I. MODELOWANIE ROZWOJU SIECI

Streszczenie. Opracowano zależności opisujące rozwój wiejskich sieci elektroenergetycznych w postaci nadającej się do praktycznego wykorzystania w lokalnym planowaniu energetycznym na terenach Polski południowej. W pracy przedstawiono również koncepcję rozwoju tych sieci, w której wykorzystuje się zaproponowane zależności.

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