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# IDENTIFICATION OF INDEXES DESCRIBING THE RELIABILITY OF ELECTRIC POWER SUPPLY TO RURAL CUSTOMERS

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**Summary.** A set of indexes was established which accurately describe the reliability of electric power supply to rural customers and, at the same time, are easy to determine and unify. Indexes were identified according to the criteria of universality, variability and importance. On the basis of the selected indexes, territorial differentiations in the continuity of electric power supply to customers in the rural areas of southern Poland were analysed using the linear ordering method.

**Key words:** electric power, reliability of power supply, set of indexes

## INTRODUCTION

The infrastructure of rural areas is of tremendous importance to the development of villages and agriculture, and the electric power infrastructure is one of its most important elements, on which the development of the remaining elements is dependent. The existing rural electric power infrastructure was largely built using the cheapest overhead lines with bare conductors and overhead pole transformer stations that are particularly vulnerable to failures caused by weather factors [Ocena ... 2005; Niewiedział E., Niewiedział R. 2006; Statystyka elektroenergetyki polskiej 2005; Trojanowska 2007b].

According to the applicable legal provisions, territorial self-governments and electric distribution companies should co-operate to ensure continuous and reliable electric power supplies to customers [Dz. U. nr 13 z 1996 r.; Dz. U. nr 54 z 1997 r; Polityka Energetyczna Polski do roku 2025]. The reliability of power supply depends to a large extent on the reliability of the electric power system, which determines the capacity of electric power networks to deliver to customers the agreed quantities of power (sufficiency of the system) of certain quality (power quality) without any interruptions of power supply (reliability of power supply) [Duniec 2004; Paska 2004; Trojanowska 2003b]. An interruption of power supply is defined here as the condition when the supply voltage in the electric power network is lower than 1% of its rated voltage [PN–EN 50160].

Interruptions of power supply are classified as:

- scheduled interruptions, which are notified to customers well in advance and which are caused mainly by the need to perform scheduled repairs and maintenance works on networks,
- accidental (unscheduled) interruptions, which are caused e.g. by permanent or temporary faults related mainly to external events, damage to equipment or disturbances of its operation. Because of their duration, they are divided into short interruptions of up to 3 minutes and long interruptions exceeding 3 minutes.

Interruptions in electric power supply are unavoidable, because ensuring 100% reliability of power supply would involve huge investment expenses, which is economically unprofitable. However, interruptions of power supply are the cause of financial losses for both electric power consumers and suppliers [Chojnacki 2009; Hanzelka 2003; Markiewicz 2002; Popczyk 2004; Targosz 2003]. In order to minimise the losses, electric power providers analyse the failure frequency of the network and look for failure causes and ways to improve power supply reliability. In order to evaluate the failure frequency of the network, it is necessary to provide indexes describing power supply continuity.

The aim of the work was to determine the indexes which efficiently identify the reliability of electric power supply to rural customers and, at the same time, are easy to determine and unify, and then to carry out an electric power supply quality analysis for rural areas of southern Poland with the use of these indexes.

## MATERIAL AND METHODS

The indexes that characterise the continuity of electric power supply and are used most often in international regulatory practice include [Paska 2004]:

System Average Interruption Frequency Index (SAIFI) – defined as the ratio of the total number of unscheduled long breaks during the year to the number of customers connected to the network;

a) Customer Average Interruption Frequency Index (CAIFI) – defined as the ratio of the total number of unscheduled interruptions during the year to the number of disconnected customers.
b) System Average Interruption Duration Index (SAIDI) – described as the ratio of the annual sum of the durations of all long interruptions (in minutes) to the total number of customers connected to the network.
c) Customer Average Interruption Duration Index (CAIDI) – calculated as the total sum of the durations of all long interruptions of power supply to customers (in hours) divided by the number of all customer disconnections.
d) Average Service Availability Index (ASAI) – defined as the ratio of time during the year (in customer-hours) when power supply was available to the time when there was demand for it;
e) Average Interruption Frequency Index (ASUI) – defined as the ratio of time during the year (in customer-hours) when power supply was unavailable to the time when there was demand for it.
f) Average Energy Not Supplied (AENS) – defined as the ratio of power not supplied to customers during the year to the number of customers connected to the network.
g) Momentary Average Interruption Frequency Index (MAIFI) – defined as the ratio of the total number of unscheduled short interruptions during the year to the number of customers connected to the network.

The statistical data of Polish power plants contain values of the average duration of long interruptions and the average duration of interruptions in electric power supply per one customer as well as the amount of damage per 100 km of the line, which is defined as the ratio of the number of all unscheduled long interruptions during the year to the total line length (IDL).

This work evaluates the suitability of the aforementioned indexes for the description of the reliability of electric power supply to rural customers by creating a set of decisive characteristics on the basis of the criteria of universality, variability and importance.

The indexes identified in this manner were later used in the analysis of territorial differentiation in the quality of electric power supply to customers in the rural areas of southern Poland using the linear ordering method.

Calculations and analyses were performed on the basis of results of research being conducted by employees of ENION GRUPA TAURON S.A. in the rural areas of Małopolska. The areas covered by this research are located within the power supply service area of 10 distribution districts. The distribution districts under analysis are responsible for the supply of electric power to 446,800 rural customers, to whom power is supplied via 9,900 km of the medium voltage (MV) line, 21,600 km of the low voltage (LV) line and 7,000 MV/LV transformer stations. Those customers use up approx. 1330 GWh of electric power per annum. Electric power consumption per one transformer station amounts to approx. 190 MWh and is three times as low as in the city.

## RESULTS

### Analysis of the suitability of indicators describing the reliability of power supply

For years attempts have been made to ascertain the indexes that identify well the reliability of power supply and, at the same time, are easy to determine. In the current situation, it seems that this kind of works should be continued, because each customer has the right to choose their electrical power provider freely, for which he needs, among others, information on the reliability of power supply.

On the basis of the data concerning the condition of electrical equipment, which are currently being collected by electric power providers, it is possible to determine SAIFI, SAIDI, CAIDI, AENS and MAIFI indexes as well as the value of the IDL index. Their characteristic values obtained as a result of measurements conducted in 2007 are presented in Table 1.

Table 1. Indexes characterising the continuity of electric power supply to rural customers and their variability $\varepsilon$

| Index | Value | | | $\varepsilon$ [%] |
|---|---|---|---|---|
| | Minimum | Maximum | Average | |
| IDL [number of long interruptions per 100 km of the line] | 3.1 | 216.9 | 46.0 | 141.45 |
| SAIFI [number of long interruptions per customer] | 0.0 | 0.1 | 0.03 | 147.0 |
| SAIDI [average time of long interruption per customer in minutes] | 0.5 | 15.2 | 4.2 | 116.8 |
| CAIDI [average time of long interruption in hours] | 1.8 | 8.5 | 4.5 | 49.4 |
| AENS [power not supplied to the customer in kWh] | 0.6 | 4.9 | 3.1 | 40.2 |
| MAIFI [number of short interruptions per customer] | 0.0 | 0.15 | 0.03 | 157.9 |

It was decided that, out of those six indexes, only those complying with the following criteria should be selected:

a) universality – their importance and significance should be commonly recognised,
b) variability – they should not be similar in terms of information about objects, with the high discrimination capacity being shown by characteristics marked by high variability,
c) importance – high values are difficult to achieve for them.

In this work, the variability coefficient $c$ is used for the evaluation of the spatial variability of indexes (characteristics) and it is required that the variability of indexes be higher than the arbitrarily accepted value, i.e. 10% [Ostasiewicz 1999].

The importance of characteristics was evaluated on the basis of convexity of distribution functions. The algorithm of determination of the convexity of the empirical distribution function is as follows [Ostasiewicz 1999]:

a) characteristics $X_j$ (j = 1,2,...,m) are transformed according to the formula:

$$x_{ij} := \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \quad i = 1,2,...,n; \qquad j = 1,2,...,m, \tag{1}$$

and the characteristic assumes values from the interval [0,1],

a) transformed values of the characteristic are arranged in the increasing order and the median is calculated,
b) the index $t_j$ is determined, where:

$$t_j = 1 - \sum_{(i:x_{ij} \le Me_j)} w_{ij} \quad j = 1,2,..., m, \tag{2}$$

where:

$$w_{ij} = \frac{1}{n}. \tag{3}$$

The classification is carried out on the basis of the value of $t_j$. The importance of the characteristic grows as the value of $t_j$ decreases, and the threshold value of this index is assumed on the level of 0.5. Figure 1 presents examples of charts of empirical distribution functions for the average annual quantity of electric power not supplied to the customer during the year (AENS) and the average number of short interruptions per customer (MAIFI), where the former is an important feature and the latter is not.

According to the above-discussed criteria of universality, variability and importance, SAIFI, SAIDI, CAIDI and AENS indexes were included in the set of decisive characteristics determining the reliability of electric power supply to rural customers.

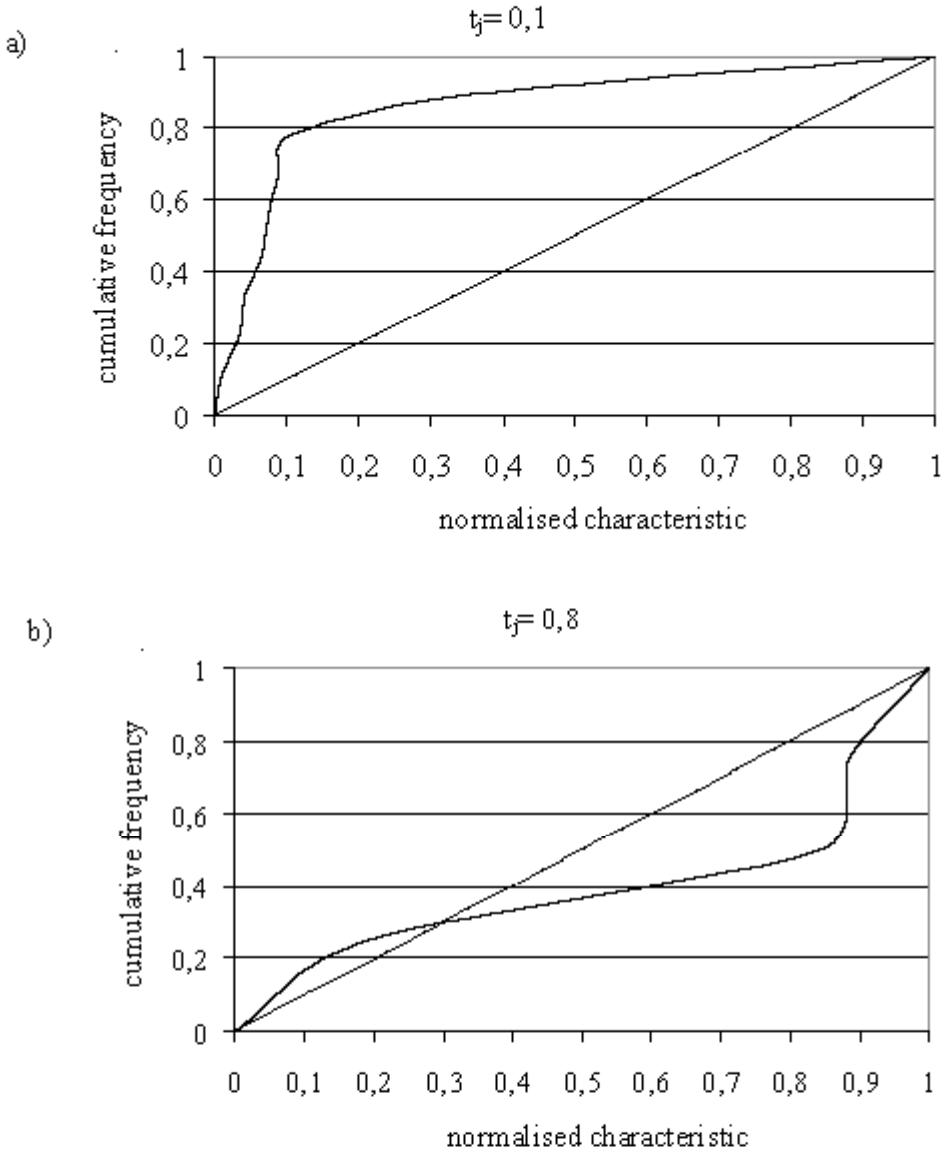


Fig. 1. Empirical distribution function for:
a) AENS – important characteristic, b) MAIFI – unimportant characteristic

**Comparative analysis of power supply quality**

The performed calculations suggest that indexes characterising the reliability of power supply that are determined separately for rural areas served by various power supply districts are substantially different from each other, which is reflected by high values of coefficients of variability of indexes $e$, which reach approx. 160% (Table 1).

For the evaluation of territorial differentiation of the reliability of electric power supply to rural customers in the areas of southern Poland under analysis, the linear ordering method was used. For each of the power supply districts, SAIFI, SAIDI, CAIDI and AENS indexes, or actually their inverses, were calculated and treated as characteristics with attributes of stimulants. The ranking of districts in terms of the reliability of power supply to rural customers was prepared by assigning to each district Hellwig's measure $d_i$ as a synthetic variable used most often in practical research, with the following relation being used [Trojanowska 2007a]:

$$d_i = 1 - \frac{d_{i0}}{d_0}, \qquad i = 1,2,\ldots,n, \tag{4}$$

where:

$$d_{i0} = \sqrt{\sum_{j=1}^{p} \left(x_{ij} - x_{0j}\right)^2}, \tag{5}$$

$$d_0 = \bar{d}_0 + 2 \cdot \sqrt{\frac{1}{n} \sum_{i=1}^{n} \left(d_{0i} - \bar{d}_0\right)^2}, \tag{6}$$

while:

$$\bar{d}_{0i} = \frac{1}{n} \sum_{i=1}^{n} d_{i0}, \tag{7}$$

where: $x_{ij}$ – value of the standardised characteristic with attributes of a stimulant,
$x_{0j}$ – maximum value from the set of characteristics.

The measure $d_i$ is constructed in such a manner that the closer its values are to unity, the less distant the given object is from the standard, which is also called the upper pole of the set of objects. The characteristic feature of synthetic measures is the fact that the replacement of the description of objects with a synthetic characteristic by means of many characteristics makes it possible to prepare their classification, which is based, in this case, on the division of the set of objects into classes according to one characteristic only.

The analysis of the determined values of the synthetic variable $d_i$ made it possible to divide districts into 3 groups (Fig. 2.). It turned out that the highest failure rate for electric power supply occurs in the north-eastern part of the area under analysis, which is served by the district distribution Bochnia, Kraków-Nowa Huta, Kraków-Podgórze and Tarnów Teren.

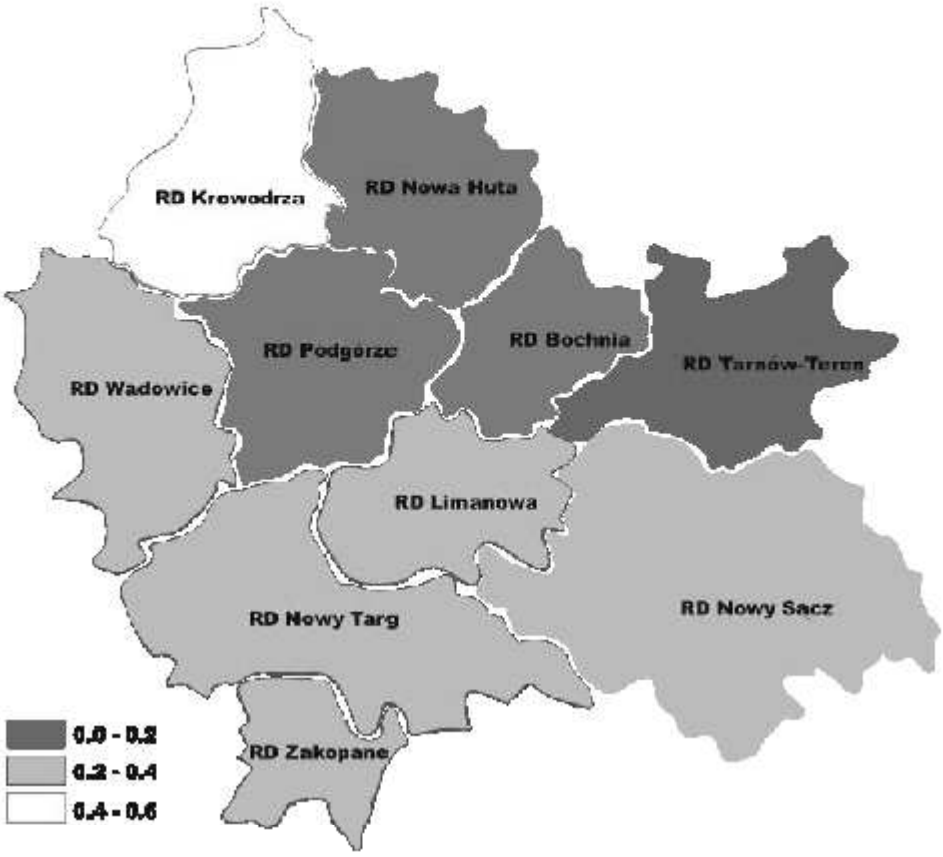


Fig. 2. Territorial differentiation of the reliability of electric power supply to customers in the rural areas of southern Poland

## CONCLUSIONS

On the basis of the performed calculations, it was found that the continuity of electric power supply to rural customers is best characterised by indexes such as: the average number of long interruptions per customer (SAIFI), average annual duration of long interruptions per customer (SAIDI), average duration of long interruption (CAIDI) and the average annual quantity of power not delivered to the customer (AENS). The above-mentioned indicators are used in international regulatory practice and are determinable on the basis of operating measurements carried out by Polish power engineering companies.

Analyses performed on the basis of identified indexes confirmed earlier reports of unsatisfactory quality of electric power supply to customers in the rural areas of southern Poland [Trojanowska 2003a, 2003b, 2004, 2007a; Trojanowska, Nęcka 2007], particularly in its north-eastern border areas.

## REFERENCES

Duniec J. 2004.: Ciągłość zasilania – zadania dostawcy energii. [online]. [dostęp 21.11.2007]. Dostępny w Internecie: http://www.miedz.org.pl/doc/1pqisn04.pdf.

Chojnacki A.: 2009. Analiza skutków gospodarczych niedostarczenia energii elektrycznej do odbiorców indywidualnych. Wiadomości Elektrotechniczne 9.

Hanzelka Z.: 2003. Jakość energii w warunkach rynku energii. Biuletyn URE 5/2003.

Markiewicz H. 2002.: Niezawodność dostaw i jakość energii elektrycznej jako kryterium wyznaczające sposoby zasilania odbiorców i wykonania instalacji elektrycznych. PCPM 11. Wrocław. s. 1–26.

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.

Ostasiewicz W. (red). 1999.: Statystyczne metody analizy danych. Wydawnictwo Akademii Ekonomicznej we Wrocławiu. Wrocław.

Paska J. 2004.: Jakość zasilania. Elektroenergetyka 4. s. 1–10.

Polska Norma. PN–EN 50160.: Parametry napięcia zasilającego w publicznych sieciach rozdzielczych.

Polityka energetyczna Polski do roku 2025.: Dokument przyjęty przez Radę Ministrów 4 stycznia 2005 r. Warszawa.

Popczyk J. 2004.: Nowe spojrzenie na jakość energii elektrycznej w Polsce w warunkach urynkowienia elektroenergetyki i integracji z UE. Przegląd Elektrotechniczny 6. s. 568–571.

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

Targosz R. 2003.: Koszty złej jakości energii uzasadnieniem dla europejskiego programu LPQI Jakość I Użytkowanie Energii Elektrycznej, TO SEP, ZE Tarnów.

Trojanowska M. 2003a.: Analiza porównawcza awaryjności wiejskich sieci rozdzielczych z wykorzystaniem klasyfikacji rozmytej. Inżynieria Rolnicza 3. s. 327–333.

Trojanowska M. 2003b.: Wybrane zagadnienia ciągłości zasilania w energię elektryczną polskiej wsi. Inżynieria Rolnicza 4. s. 257–262.

Trojanowska M. 2004.: Jakość energii na terenach wiejskich. Infrastruktura i Ekologia Terenów Wiejskich 2. s. 125–131.

Trojanowska M. 2007a. Analiza statystyczna ciągłości dostaw energii elektrycznej odbiorcom z terenów wiejskich województwa małopolskiego. Problemy Inżynierii Rolniczej 3(57). s. 43–48.

Trojanowska M. 2007b.: Ocena stanu technicznego sieci elektroenergetycznych i jakości zasilania w energię elektryczną Małopolskiej wsi. Problemy Inżynierii Rolniczej 2(56). s. 133–137.

Trojanowska M., Nęcka K. 2007.: Analiza jakości napięcia zasilającego gospodarstwa wiejskie. Inżynieria Rolnicza 7(95). s. 221–227.

Ustawa z dnia 10 kwietnia 1997.: Prawo energetyczne. Dz.U. z 1997 r. nr 54 wraz z późniejszymi zmianami.

Ustawa z dnia 8 marca 1990.: o samorządzie terytorialnym. Tekst jednolity: Dz.U. z 1996 r. nr 13, poz. 74, zmiany: Dz.U. z 1996 r. nr 58, poz. 261, nr 106poz. 596, nr 132, poz. 662; z 1997 r. nr 9, poz. 43.

# IDENTYFIKACJA WSKAŹNIKÓW OPISUJĄCYCH NIEZAWODNOŚĆ ZASILANIA ENERGIĄ ELEKTRYCZNĄ ODBIORCÓW WIEJSKICH

**Streszczenie.** Ustalono wskaźniki, które dobrze opisują niezawodność dostaw energii elektrycznej odbiorcom wiejskim i równocześnie są łatwe do wyznaczania oraz unifikacji. Wskaźniki identyfikowano na podstawie kryterium uniwersalności, zmienności oraz ważności. W oparciu o wybrane wskaźniki przeanalizowano terytorialne zróżnicowania ciągłości zasilania energią elektryczną odbiorców na obszarach wiejskich Polski południowej, stosując metodę porządkowania liniowego.

**Słowa kluczowe:** energia elektryczna, niezawodność zasilania, wskaźniki