

Monitoring of low voltage grids with the use of SAIDI indexes

Streszczenie. Opracowanie przedstawia opis nowej metody ustalonego uzasadnionego poziomu kosztów operacyjnych dla Operatorów Systemów Dystrybucyjnych zawartej w nowym modelu regulacji obowiązującym na lata 2016 – 2020. Zmiany wprowadzone w 2016 roku mają doszacować koszty operacyjne przedsiębiorstw zajmujących się dystrybucją energii elektrycznej do kosztów uwzględnianych w kalkulacjach taryf na lata 2016-2020. Konsekwencją niespełnienia warunków i wskaźników zgodnie z ideą nowego systemu jest obniżenie wartości zwrotu kapitału i słaba efektywność przedsiębiorstw w obniżaniu wskaźników dotyczących czasu trwania przerw w dostarczaniu energii elektrycznej. **Monitorowanie pracy sieci średniego napięcia za pomocą wskaźników trwania przerw w dostarczaniu energii elektrycznej**

Abstract. A new method of established and justified level of operational costs for distribution network operators in a new model of regulation in force in the years 2016 – 2020 is described in this article. The changes made in 2016 are supposed to estimate operational costs of the enterprises distributing electricity to the costs taken into account in calculation of tariffs. A consequence of non-fulfilment of conditions and indexes in accordance with an idea of the new system is lowered value of return of capital and poor efficiency of enterprises in reduction of SAIDI indexes.

Słowa kluczowe: Operator Systemu Dystrybucyjnego, Wskaźniki ciągłości dostaw energii, Wskaźniki operacyjne, Urząd Regulacji Energetyki, URE, OSD, SAIFI, SAIDI, CRP, WSD.

Keywords: Distribution network operator (DNO), continuity of electricity supply rates, operational rates, Energy Regulatory Office, URE, DNO, SAIFI, SAIDI, CRP, WSD.

Introduction

European Union and Energy Regulatory Office sets the following goals for the companies from electrical power sector: continuity of electricity supply, an increase in reliability and the use of renewable sources of energy. These requirements are related to electrical power security of the states, in terms of operation and maintenance of power lines [1], [2]. Therefore, electrical power infrastructure requires larger number of inspections, repairs or complete modernization [18].

Therefore, the solutions supporting an analysis of failure frequency are required, as well as solutions that will improve switching of damaged fragments of the lines.

Distribution network operators are more and more involved in accomplishment of above goals, which results in higher quality of supplied energy.[3], [4], [14].

The basic goal of the publication is to compare SAIDI indexes and to present a new method of established and justified level of operational costs for distribution network operators.

The main causes of failures in medium-voltage lines

Medium-voltage transmission lines in Poland consist in 80% of overhead lines and in 20% of cable lines. The number of cable lines is increasing every year due to modernization and changing overhead lines into cable lines. The majority of medium-voltage lines were built in the 1970s-1980s. AFL-6 cables from 25 mm² in diameter on the branches of lines up to 70 mm² at the stem of low voltage line were usually used for the construction of overhead lines.

Due to increased power demand from the customers, diameters of the lines, particularly on the branches can be insufficient. These structures were supported by poles: ŻN (reinforced concrete), BSW (prestressed concrete), ŻW (reinforced concrete high). These rods were between 10 and 14 m high and between 1,1 and 4,4 kN of tension. The poles were equipped with supporting insulators (linear standing rod) and linear hanging rod insulators [5]. The disadvantage of overhead lines is their sensitivity to external and atmospheric factors. The birds, branches and natural process of ageing have big impact on failure frequency of overhead lines.[17] The examples of damages resulted from ageing and branches are presented on Fig. 1.

The wires, insulators and poles made of reinforced concrete are the parts that are usually damaged. The

percentage share of these elements in damaged lines in total is presented on Fig.2. The majority of damages is caused by the time that elements of medium-voltage lines are used. The structures and drives of switchgears corrode and break down with time.



Fig.1. The examples of damages to overhead lines: the ageing of the structure [15], and damages caused by branches of trees [16]

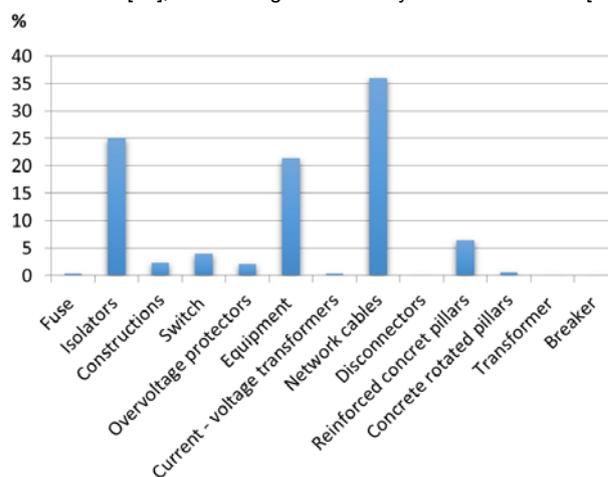


Fig.2. The percentage share of damages of particular elements of low voltage lines

Another cause of failure, not resulting directly from the age of a line, is insufficient number of cutting of trees and branches close to the lines. It is often caused by formal and legal problems with the access to real estate. The falling of a tree or branches on the line can damage wires, pole structure and even the very poles.

Above deliberations are confirmed by an analysis of SAIDI (System Average Interruption Duration Index) in 2015 for three selected departments from central Poland. The longest interruptions in electricity supply were caused by material ageing, and then by trees and branches and atmospheric discharges. SAIDI indexes divided into causes of failures for three departments are presented on Fig.3.

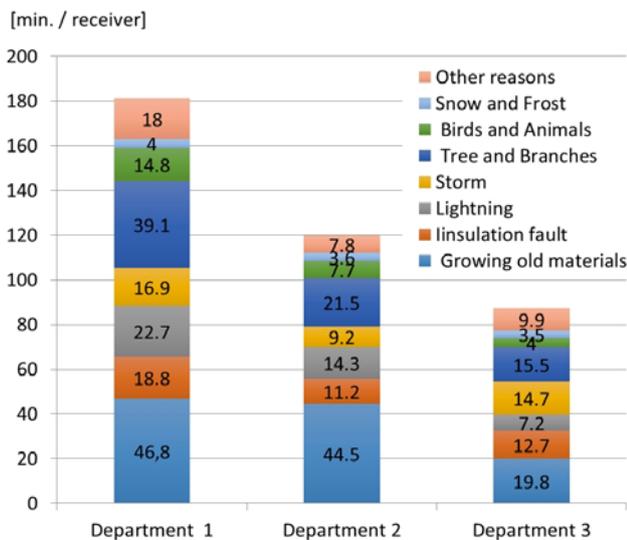


Fig.3. SAIDI indexes unplanned with catastrophic ones divided into causes of failures for three selected departments [6]

SAIDI indexes in urban and rural areas are presented in table 1. About 80% of failures occur in rural areas. It is probably caused by the fact that majority of low voltage lines in urban areas is cabled, which limits occurrence of such failure frequency factors as „trees and branches”, „gales”, „birds and animals”.

Table 1. SAIDI indexes planned and unplanned with catastrophic ones divided into rural and urban areas for three selected departments [6]

		Department 1	Department 2	Department 3
Urban area	Planned	24,2	32,3	9,2
	Unplanned with catastrophic	84,5	53,9	51,8
Rural area	Planned	164,8	132,7	56
	Unplanned with catastrophic	362	227	212

Apart from limiting the impact of external factors on medium-voltage lines in urban area, the high impact on reaction to failures and restoration of power has ring work system and an option of quick disconnection of damage fragment of a line. Switching is made with the use of radio-controlled switch disconnectors placed in a few places of medium-voltage lines. They enable to section off even the smallest fragment of a failed line. The location of radio-controlled switch disconnectors is also important. They are supposed to reduce the number of transformer stations without power supply during failure. 3 departments in terms of their SAIDI index in an urban area were compared on Fig. 4 and in rural areas on Fig. 5.

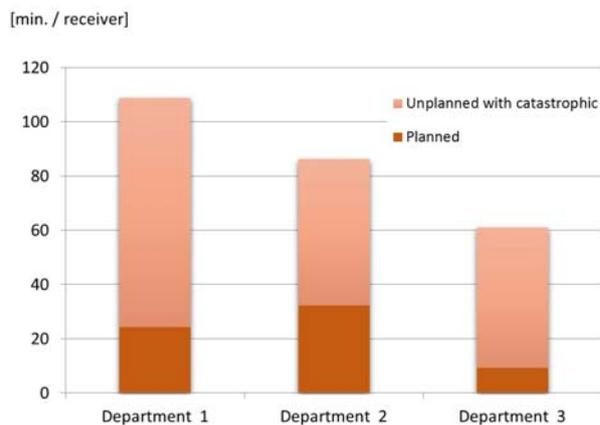


Fig.4. SAIDI indexes planned and unplanned with catastrophic ones in urban area for three selected departments [6]

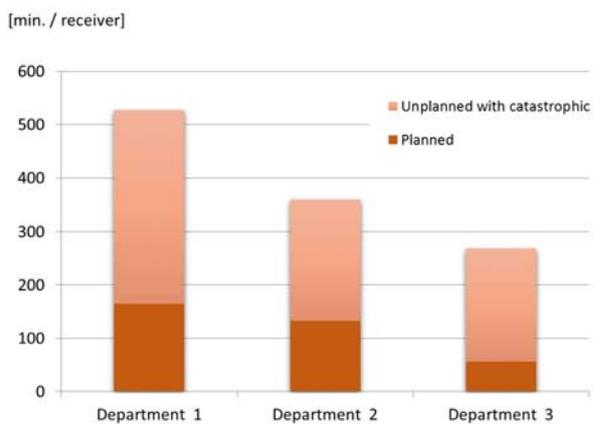


Fig.5. SAIDI indexes planned and unplanned with catastrophic ones in rural area for three selected departments [6]

The comparison of indexes monitoring medium-voltage failure frequency

An order of the Minister of Economy on the conditions of functioning of electrical power system imposes an obligation to reveal SAIDI indexes on distribution network operators [7]. Publishing data is an assessment of efficiency of enterprises and it is supposed to increase quality of services of distribution of electricity, maintaining price affordability of these services, and current level of investments.

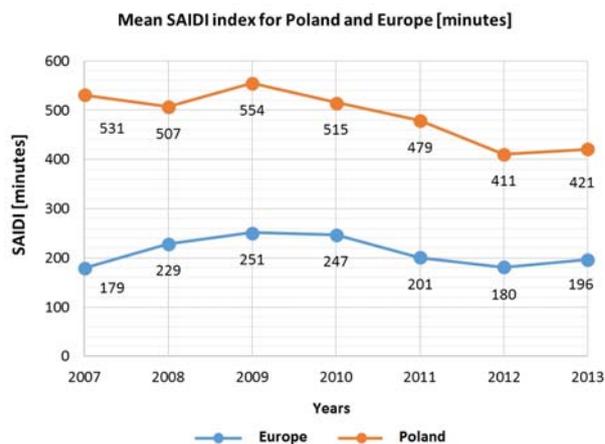


Fig.6. Mean SAIDI index calculated as the sum of planned and unplanned interruptions, including interruptions caused by disasters, for selected countries of Europe, and Poland from 2007 – 2013 [8], [9]

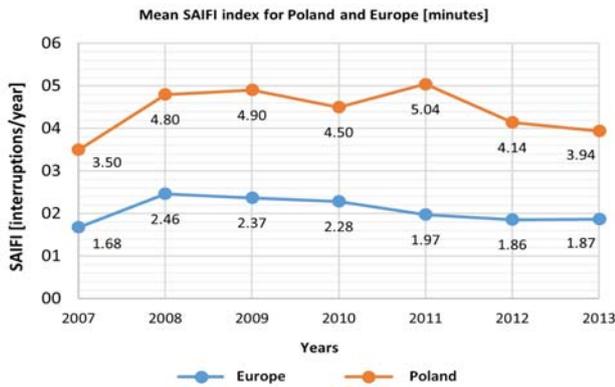


Fig.7. Mean SAIFI index calculated as the sum of planned and unplanned interruptions, including interruptions caused by disasters, for selected countries of Europe, and Poland from 2007 – 2013 [8], [9].

The level of capital expenditures of 4 largest electrical power DNOs has considerably increased in recent years. It is estimated that this level increased in the years 2009-2014 by over 50% [8]. Despite these investments, the level SAIDI and SAIFI (*System Alergen Interruption Frequency Index*) indexes in Poland still differ from European average. The comparison of average SAIDI and SAIFI indexes in the years 2007-2014 in Poland and selected European countries is presented on Fig.6 and Fig.7. SAIDI and SAIFI indexes for the largest five distribution network operators in 2015 are presented on Fig.8 and Fig.9.

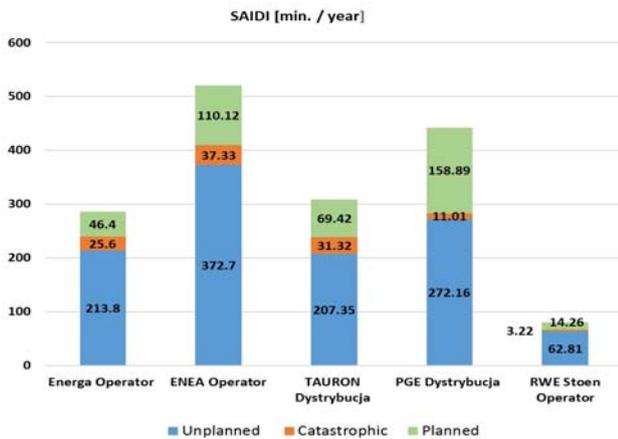


Fig.8. SAIDI index divided into type of interruptions for the largest five distribution network operators in 2015

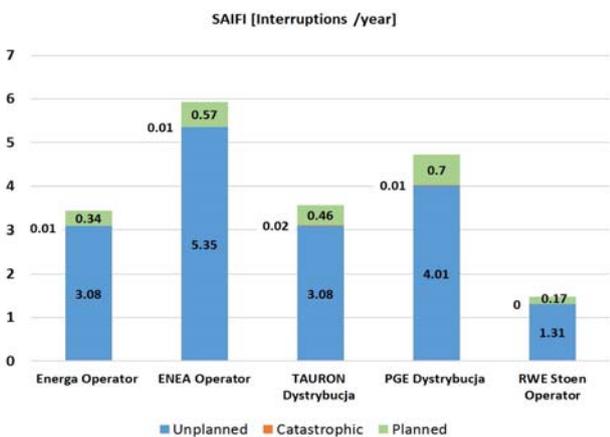


Fig.9. SAIFI index divided into type of interruptions for the largest five distribution network operators in 2015

Due to big differences between Poland and other European countries and due to necessity to improve the quality of services provided by the Operators, the director of Energy Regulatory Office decided to introduce a new model of regulation for the years 2016 – 2020. The improvement of quality of services of distribution of electricity provided for customers should be the main goal. The works on implementation of a new regulation began in 2014. The director of Energy Regulatory Office obliged five largest DNOs to install balancing meters in medium and low voltage stations. The number of installed meters is supposed to correspond to specific representative group of customers at the end of 2015, that is, about 51% of customers and minimum 80% of customers in 2018. It will enable to determine, among others, duration of interruptions in electricity supply on low voltage side [10]. Looking ahead, it will be possible to measure on its basis, among others, the duration of supply interruptions on low voltage side and, as a result, to take appropriate actions by DNO to increase the quality of services of distribution of electricity provided to customers.

The emphasis will be put on the improvement of quality of services of distribution of electricity provided to customers, and the indexes having direct impact on income of DNO will be SAIDI and SAIFI indexes, adjusted for the purposes of qualitative regulation and index illustrating Connection Realization Time (CPR) of 4th and 5th energy consumer group. In 2018, Transmission of Metering and Billing Data Time (CPD) read from data interchange system in ebIX standard will be added to a new model of regulation.

The rules of calculating regulated income in a new model in a enterprise dealing with distribution of electricity are determined with the use of following dependency [8]:

$$(1) \quad PR = K_o + A + P_s + K_{zk} + K_{RB} + T_e + K_p + P$$

where: PR – regulated income, K_o – operating costs, A – amortization, P_s – power grid assets tax, K_{zk} – the costs of capital employed, K_{RB} – the costs of balance difference, T_e – the costs of transit of energy, K_p – the costs of purchase of transmission services to OSP, P – remaining elements of regulated income.

In a model in force in the years 2011 – 2015, the value of return on capital employed in a tariff for a given year was determined by dependency (2):

$$(2) \quad K_{zk} = WRA_t * WACC_t$$

where: K_{zk} – return on capital employed in a tariff in t year, WRA_t – regulating asset value for t year (with AMI investments), $WACC_t$ – weighted average cost of capital established for t year (increased by 7% for AMI investments).

The method of calculating return on capital employed has changed in a model, which will be in force in the years 2016 - 2020. A dependency (3) describing the method of calculating the costs of capital employed is presented below:

$$(3) \quad K_{zk} = WRA_t * WACC_t * Q_t * WR_t$$

where: K_{zk} – return on capital employed in a tariff in t year, WRA_t – regulating asset value for t year (with AMI investments arranged with the director of URE until March 31, 2015), $WACC_t$ – weighted average cost of capital established for t year (increased by AMI investments arranged with the director of URE until March 31, 2015 o 7%), Q_t – qualitative regulation coefficient, WR_t – regulating rate.

Two new coefficients were introduced in comparison with previous model:

- qualitative regulation coefficient Q_t between 0,85÷1,0 taking lack of appropriate effects of qualitative regulation into account,
- regulating rate WR_t (determined individually for each DNO) between 0,9 ÷ 1,1 taking assessment of innovative character of actions taken by DNO into account.

Operational costs of distribution network operators

One of the main factors accepted in a new model of calculating regulated income is a rate of operational costs. Between 2008 and 2014, distribution network operators had higher costs than were taken into account in calculation of tariffs for the analysed period. These costs were higher in the years 2008 – 2014 by 20,7% and by 7,8% in the years 2012 – 2014. In 2014, only three operators had lower costs [11]. Taking actions of DNOs within the scope of efficiency improvement into account, efficiency improvement was checked by determining arithmetic mean of operational costs analysed in the years 2008 – 2014 in prices for the year 2015 for each DNO. Calculated mean value was reduced by the costs of assumed efficiency improvement. The costs assumed for the year 2020 do not take only efficiency improvement of DNOs into account, but also forecasted action scale growth of operators.

Taking energetic interests of enterprises and customers into consideration, the costs resulting from a new model for the years 2016 -2020 with the costs taken into account in calculation of tariffs in 2015 were combined. Assuming the costs expressed in permanent prices in 2015, the following formula (4) can be applied to determine the costs for a given year of regulation period 2016 - 2020:

$$(4) \quad K_{tax\ t} = K_{tax\ 2015} \cdot \left[I + \left(\sqrt[5]{\frac{K_{model\ 2020}}{K_{tax\ 2015}} - I} \right) \right]^{(t-2015)}$$

where: $K_{tax\ t}$ – the costs to be taken into account in calculation of tariffs, t – another year of tariff t (2016, 2017, 2018, 2019, 2020), $K_{tax\ 2015}$ – model costs taken into account in calculation of tariff of an enterprise for the year 2015, $K_{model\ 2020}$ – model costs in 2020 (in prices from 2015), resulting from a new model of assessment of operational costs, taking efficiency improvement and action scale growth of the enterprises into consideration.

Above formula was in effect until 2016, whereas the dependency defined in §21.1 of the publication [12] should be used to determine tariff costs in the years 2017 – 2020:

$$(5) \quad Kw_n \leq Kw_{n-1} \cdot [I + (RPI - X_n) / 100]$$

where: Kw_n, Kw_{n-1} – prime costs of an energy enterprise related to business activity, taking conditions of such business activity into consideration, X_n – correction coefficients defining efficiency improvement of an energy enterprise, determined for particular years in a year of extending the tariff for confirmation [%], RPI – annual average rate of prices of consumer goods and services in total, in a calendar year preceding a year of working out a tariff [%].

The value of correction coefficients X_n for the years 2017-2020 is determined from the dependency (6) which is enabled by application of a new method of establishing justified level of operational costs:

$$(6) \quad X_n = - \left(\sqrt[5]{\frac{K_{model\ 2020}}{K_{tax\ 2015}} - I} \right)$$

To apply a new method of established and justified level of operational costs, it is required to calculate the level of effective costs in the years 2008-2014. The following dependency is applied for this purpose (7):

$$(7) \quad K_{Et} = K_{Bt} \cdot (I - PE_{KI}) \cdot (I - PE_{KS})$$

where: K_{Et} – the level of effective costs in t year, K_{Bt} – base costs of t year, PE_{KI} – individual efficiency improvement coefficient between 2016 and 2020, PE_{KS} – sector efficiency improvement coefficient between 2016 and 2020.

A base cost is an operational cost of distribution, that is, distribution costs excluding amortization, the costs of energy purchase to cover balance sheet difference, the costs of purchase of distribution and transmission services, the costs of power grid assets tax and concession fees. A base cost is reduced by the costs of:

- the fees for perpetual usufruct of land in the field of power grid assets,
- the fees for permanent land exemption from an agricultural use,
- the fees for transmission easement for state-owned forests,
- the fees for placing devices of technical infrastructure or buildings on a roadway,
- the costs of workers' tariff,
- the costs resulting from changing the state of actuarial reserves on account of workers' tariff,
- the costs resulting from the change in actuarial reserves on other accounts,
- one-off costs of Voluntary Redundancy Programs and other one-off costs.

The value of model costs in the years 2008-2014, $K_{model\ 2008-2014}$, was calculated as arithmetic mean of discounted effective costs (from the years 2008-2014) for the year 2015.

It was also necessary to check the impact of mean DNO action scale growth on the costs of enterprises in the years 2016-2020 and potential new obligations of DNO by applying action scale growth coefficient (WSD).

Model costs in 2020, $K_{model\ 2020}$, taking efficiency improvement and DNO action scale growth into account, was calculated in accordance with the following formula (8):

$$(8) \quad K_{model\ 2020} = K_{model\ 2008-2014} \cdot (I + WSD)$$

where: $K_{model\ 2020}$ – model costs in 2020, resulting from a new model of assessment of operational costs, taking efficiency improvement and action scale growth of the enterprises into consideration, WSD – action scale growth rate.

The application of a new method of established and justified level of operational costs requires the knowledge of base costs of DNO in the years 2008-2014 and the value of sector efficiency improvement coefficient in the years 2016-2020, which was determined at the level of $PE_{KS} = 10\%$. An individual efficiency improvement coefficient between 2016 and 2020 for all DNOs was assumed as $PE_{KI} = 0$ [13]. The value of action scale growth rate in the years 2016-2020, $WSD = 2,5\%$.

Conclusions

With reference to low voltage energy infrastructure, the major cause of failures is old devices, trees, atmospheric phenomena. The distribution network operators systematically try to modernize lines to improve the first cause. However, this process requires time and financial outlays. The second cause of failures is eliminated by DNOs by cutting trees in the vicinity of power lines. However, it is sometimes not possible, because the access to real estate is often difficult for formal and legal reasons. DNOs can't do too much to eliminate the third cause. Therefore, the goal is to limited the time of failure and number of medium-voltage lines and transformer stations left without power supply during removal of failure. SAIFI and SAIDI indexes are good determinants of effectiveness of these actions.

The list of SAIDI and SAIFI indexes for five distribution network operators in the years 2011-2015 is presented in the thesis. The situation is improving every year. Based on attached charts, we can see the emphasis that DNOs put on reduction of these indexes.

It is necessary to implement a new model of regulation to increase quality of services provided by distribution network operators. The implementation of qualitative regulation is both chance and challenge for distribution companies. It gives operators an opportunity to improve their image and increase efficiency of enterprises. Another benefit from implementation of a new regulation DNO, taking the state of power grids into account, will be a plan of network investments, new sources of energy, showing the areas recommended to modernization and rebuilding.

Autorzy: *prof. dr hab. inż. Zbigniew Łukasik, Uniwersytet Technologiczno-Humanistyczny, Wydział Transportu i Elektrotechniki, ul. Malczewskiego 29, 26-600 Radom, E-mail: z.lukasik@uthrad.pl; dr inż. Jacek Kozyra, Uniwersytet Technologiczno-Humanistyczny, Wydział Transportu i Elektrotechniki, ul. Malczewskiego 29, 26-600 Radom, E-mail: j.kozyra@uthrad.pl; dr inż. Aldona Kuśmińska-Fijałkowska, Uniwersytet Technologiczno-Humanistyczny, Wydział Transportu i Elektrotechniki, ul. Malczewskiego 29, 26-600 Radom, E-mail: a.kusmińska@uthrad.pl.*

REFERENCES

- [1] Kozyra J.: Monitorowanie i diagnozowanie uszkodzeń w procesach wytwarzania i przesyłu energii elektrycznej. *Logistyka*, 3/2015
- [2] Kuśmińska-Fijałkowska A., Łukasik Z.: Efekty wynikające z wdrożenia Systemu Zarządzania Jakością. *Logistyka* 3/2014
- [3] Kuśmińska-Fijałkowska A., Łukasik Z.: Koordynowanie działań w organizacji w odniesieniu do Systemu Zarządzania Jakością. *Logistyka* 3/2014
- [4] Kozyra J., Warchoń R.: Wykorzystanie energoelektronicznych systemów zasilania gwarantowanego AC w elektroenergetyce. *Logistyka* 6/2014
- [5] Elprojekt Sp. z o.o., Album linii napowietrznych średniego napięcia 15-20 kV, Poznań 2011
- [6] Opracowanie na podstawie statystyk OSD
- [7] Rozporządzenie Ministra Gospodarki z dnia 4 maja 2007 Dz.U. Nr 93, poz. 623
- [8] Putynkowski G., Balawender P., Woźny K., Kozyra J., Łukasik Z., Kuśmińska-Fijałkowska A., Ciesielka E.: A New Model for the Regulation of Distribution System Operators with Quality Elements that Include the SAIDI/SAIFI/CRP/CPD Indices. *Electrical Power Quality and Utilisation*, Journal Vol. XIX, No. 1, 2016, ISSN: 1896-4672
- [9] CEER Benchmarking Report 5.2 on the Continuity of Electricity Supply. Data update, Council of European Energy Regulators, Brussels 2015.
- [10] Strategia Regulacji Operatorów Systemów Dystrybucyjnych na lata 2016-2020 (którzy dokonali z dniem 1 lipca 2007 r. rozdzielenia działalności), Urząd Regulacji Energetyki Warszawa 2015 r.
- [11] Koszty operacyjne dla Operatorów Systemów Dystrybucyjnych na lata 2016-2020 (którzy dokonali z dniem 1 lipca 2007 r. rozdzielenia działalności) Urząd Regulacji Energetyki Warszawa 2015 r.
- [12] Rozporządzenie Ministra Gospodarki z dnia 18 sierpnia 2011r. w sprawie zasad kształtowania i kalkulacji taryf oraz rozliczeń w obrocie energią elektryczną. (Dz.U. z 2013 r. poz.1200)
- [13] Osiewalski J., Makiela K.: Koncepcja ustalania wybranych elementów kształtujących Przychód Regulowany OSD, którzy dokonali z dniem 1 lipca 2007r. rozdzielenia działalności – model kosztów operacyjnych i różnicy bilansowej, Kraków 2015.
- [14] Szmurło R., Starzyński J., Chaber B., Wincenciak S.: Flexible Scenarios Based System for Scientific Computing. *Przegląd Elektrotechniczny* Tom 88 nr. 4a, pp.117-119. (2012)
- [15] <http://www.operator.enea.pl>
- [16] <http://wm.pl/>
- [17] Krysiuk, C., J. Brdulak, B. Zakrzewski. Bezpieczna infrastruktura w transporcie drogowym. *Logistyka* 4 (2014).
- [18] Wójcik W.: *Modern Power Engineering.1*, Monografia, s.197 Politechnika Lubelska 2011