Anna GAWLAK
Politechnika Częstochowska, Instytut Elektroenergetyki

doi:10.15199/48.2019.08.04

Profitability analysis of investment projects in distribution networks

***Abstract**. The equipment of many distribution companies in Poland is old, therefore investment projects should be implemented to modernize it. One of the key parameters that should be taken into account is energy loss. In the distribution network the highest loss is attested in meters, LV, MV and HV lines and in MV/LV transformers. This paper deploys the methods of SPBP, IRR and NPV to present an analysis of effectiveness of investment projects. The analysis is based on real input data from two distribution companies in Poland.*

Streszczenie.** Majątek spółek dystrybucyjnych jest w Polsce stary, wymaga więc modernizacji. Jednym z parametrów mających wpływ na inwestycje sieciowe są straty energii elektrycznej. Największe straty energii w sieci rozdzielczej występują w licznikach energii elektrycznej, liniach sieci niskiego, średniego i wysokiego napięcia oraz w transformatorach SN/nN. Na przykładzie jednego z obszarów dystrybucji, pokazano analizę efektywności inwestycji przy użyciu metod SPBP, IRR oraz NPV. **(Analiza rentowności inwestycji w sieciach dystrybucyjnych).

Słowa kluczowe: sieć dystrybucyjna, efektywność energetyczna, inwestycje sieciowe, straty energii.
Keywords: distribution network, energy efficiency, network investments, energy losses.

Introduction

The most important characteristic feature that distinguishes investment in the power sector from other branches of industry is that it is a long-lasting and complicated process. This is related to a relatively long life of the elements of the power system. Polish distribution networks include elements which have been heavily exploited and require replacement or modernization [1-3]. Another feature typical of investment in the power industry is a relatively long period of return on invested capital. Besides, the capital expenditure and cost of investment are also relatively high. Table 1 presents the age structure of selected elements of the power grid for the five biggest Polish distribution companies (OSD) as of end of 2017 [4].

Table 1. Age structure of selected network elements [%]

Network elements	> 40 years old	25-40 years old	10-25 years old	< 10 years old
HV overhead	42	34	15	9
HV cable	0	3	17	80
HV/MV substations	30	33	20	17
HV/MV transformers	19	33	19	29
MV overhead	37	39	17	7
MV cable	16	24	28	31
MV/LV substations	28	32	22	19
MV/LV transformers	15	29	25	31
LV overhead	31	35	21	13
LV cable	13	25	31	31

The necessity of making investment in the power industry is motivated mostly by the fact that the transmission and distribution networks include worn-out elements and are largely ineffective, with high loss and low reliability. About 25% of the network equipment is more than 40 years old, and another 25-30% is over 25 years old.

The directions of development for the distribution network are as follows [5-10]:

- reducing energy loss in distribution transformers and networks,
- modernizing and expanding the 110 kV distribution network and networks of lower voltages with a view to the following:
  - minimizing technical and commercial loss,
  - increasing reliability,
  - expanding the network in order to offer services to a greater number of customers,
  - connecting renewable energy sources.

Reducing energy loss by investment

The study was carried out on the basis of data obtained from a power company covering 8 distribution companies (OSD). The data concerned the amount of energy flowing through the particular voltage levels and the number of distribution devices. Losses energy presented in Table 2.

Table 2. Energy loss in the distribution network [GWh]

Loss	O1	O2	O3	O4	O5	O6	O7	O8
in meters	10	10	6	9	14	16	16	10
load loss in LV lines	20	9	40	23	31	25	38	11
idle in MV/LV transformers	34	30	17	26	34	37	50	20
load loss in MV/LV transf.	9	4	11	8	8	12	21	4
other tech. in LV	7	5	5	6	7	7	11	4
load loss in MV lines	77	36	90	101	59	80	184	31
other tech. in MV	7	7	5	5	7	6	7	4
load loss in 110 kV lines	26	31	33	55	63	35	55	14
in110/MV transformers	24	20	20	27	20	20	41	12

The main component of total loss, is load loss in MV lines, amounting to 33.81% in OSD3 and to 17.24% in OSD2. The MV/LV transformer loss is also high; the highest share is 17.43% of total balance loss in OSD1 and the lowest 10.63% in OSD3. Large load loss of energy in 110 kV lines is attested OSD5, where it constitutes 20.67% of total balance loss. The lowest percentage of load loss in 110 kV lines at the level of 9.20% occurs in OSD8. Load loss in LV lines range from 15.21% in OSD3 to 4.46% in OSD2, whereas loss in meters ranges from 6.45% in OSD8 to 2.11% of total balance loss in OSD3.

Electric energy loss can be reduced by taking the following actions:

- increasing cross-section area of lines,
- constructing additional MV/LV transformer substations,
- adjusting MV/LV transformer load to the amount of energy flowing through them,
- replacing induction meters by static ones,
- replacing transformers produced before 1975 by new ones.

Table 3 specifies the expected loss reduction in OSDs. The values were obtained on the basis of the following assumptions:

- The cross-section of the 110 kV line will be increased by increasing the volume of the conducting material by 120 mm^2 per 1 km of the line.

- The cross-section of the MV line will be increased by increasing the volume of the conducting material by 35 mm^2 per 1 km of the line.
- The cross-section of the LV line will be increased by increasing the volume of the conducting material by 25 mm^2 per 1 km of the line.

Table 3. Mean yearly savings of final energy output obtained by increasing line cross-section

Area unit	Mean yearly savings of final energy output obtained by increasing line cross-section					
	10 km of 110 kV line[MWh]	10% of 110 kV line [MWh]	60 km of MV line [MWh]	10% of MV line [MWh]	60 km of LV line [MWh]	10% of LV line [MWh]
OSD1	94.65	1414.99	182.99	6143.16	38.76	1254.26
OSD2	148.97	1556.71	113.00	2816.16	**71.55**	1531.01
OSD3	**381.70**	1515.37	115.77	2266.21	56.03	**4193.55**
OSD4	189.54	2484.90	389.11	9141.78	47.73	1670.23
OSD5	200.70	**3590.60**	180.75	4250.42	52.44	2193.31
OSD6	126.98	2039.26	240.04	5983.39	49.29	1926.36
OSD7	213.89	3161.22	**599.42**	**16104.77**	51.85	2307.63
OSD8	54.04	570.15	116.42	2385.17	35.16	919.12

The greatest savings can be obtained in OSD3 381.70 MWh per each kilometer of the 110 kV line. The lowest savings at the level of 54.04 MWh will be obtained in OSD8. In MV lines, the greatest savings can be achieved in OSD7, where by increasing the cross-section of 60 km of the line by 35 mm^2, 16104.77MWh of energy can be saved, whereas OSD2 will have the lowest savings. As far as the LV network is concerned, the lowest savings will be obtained in OSD8, where the cross-section increase by 25 mm^2 at 60 km of the line will yield additional 38,76 MWh in OSD1, and the greatest, equal to 71,55 MWh will be obtained in OSD2.

Table 4. Mean annual savings of final energy output – other options

Area unit	Replacing induction meters by static meters [MWh]	Increasing the number of MV/LV substations by 10% [MWh]	Replacing old transformers by new ones [MWh]	Reducing the power of existing transf.by 10% [MWh]
OSD1	4 868.39	1 858.05	**6 118.39**	1 699.21
OSD2	6 644.38	848.52	2 569.11	**1 759.44**
OSD3	3 836.57	**3 658.50**	139.17	-122.23
OSD4	3 122.20	2 090.80	1 820.78	956.40
OSD5	5 444.17	2 831.15	1 356.03	1 575.76
OSD6	**9 187.24**	2 297.25	3 718.62	1 355.19
OSD7	5 804.07	3 437.49	3 740.47	1 108.84
OSD8	5 555.26	1 036.85	1 951.74	1 030.66

Replacing induction meters by static meters will yield the greatest savings in OSD6, where the number of induction meters is the biggest. Increasing the number of MV/LV substations by 10% will contribute to saving 3658.50 and 3437.49 MWh in OSD3 and OSD7, respectively. If all transformers manufactured before 1975 are replaced, the greatest savings will be obtained in OSD1 6118.39 MWh and the smallest in OSD3 139.17 MWh. Lowering the power of existing transformers and increasing their load by 10% will yield the savings in the final energy output of 1699.21 MWh in OSD1 and of 1759.44 in OSD2. In OSD3 such a move would be unbeneficial since increase in transformer load would cause increase in energy loss. This indicates that in this company the transformer power is selected optimally with respect to the network load.

Table 5 presents the results of energy loss reduction in the particular companies.

Table 5. Mean yearly energy savings obtained by increasing the volume of the conducting material in the area

Area unit	HV network [kWh]	MV network [kWh]	LV network [kWh]	One MV/LV station [kWh]
OSD1	789	871	258	**1 609**
OSD2	1241	538	477	1 021
OSD3	**3181**	551	374	**10 010**
OSD4	1580	**1853**	318	1 749
OSD5	1673	861	350	**2 506**
OSD6	1058	1143	329	**1 758**
OSD7	1782	**2854**	346	2 101
OSD8	450	554	234	**1 164**

The highest mean savings per year at the level of 3181 kWh in the 110 kV network will be obtained in OSD3, whereas in OSD7 in the MV network the amount of energy saved will be 2854 kWh. The lowest savings of 234 kWh will be achieved in the LV network in OSD8. The effect of adding an extra MV/LV station will have the biggest impact on OSD3, contributing to saving 10010 kWh of energy. In OSD2 and OSD8 this effect will be much less conspicuous only 1021 kWh and 1164 kWh of energy saved, respectively.

The areas covered by distribution companies are relatively large, so the next part of the study was conducted for two distribution companies OSD2 and OSD7, which had the smallest and the greatest energy savings, respectively.

Table 6 shows energy loss in LV and MV networks in area units (RE) belonging to the two distribution companies. The second digit in the area number indicates the distribution company.

Table 6. Energy loss in the distribution network [MWh]

Loss [MWh]	RE12	RE22	RE32	RE42	RE17	
in meters	2 438	2 493	2 717	2 713	1 761	
load loss in LV lines	1 775	2 903	2 572	2 084	1 499	
idle loss in MV/LV	7 532	8 039	6 610	7 960	7 402	
load loss in MV/LV	894	993	1 172	1 013	5 868	
load loss in MV lines	13 709	12 511	10 778	9 087	3 552	
Loss [MWh]	RE27	RE37	RE47	RE57	RE67	RE77
in meters	2 737	3 262	1 710	2 341	1 772	2 452
load loss in LV lines	2 100	2 136	926	1 584	1 029	1 276
idle loss in MV/LV	7 937	6 422	3 722	5 588	3 226	3 515
load loss in MV/LV	10 113	9 559	5 024	7 282	5 349	7 197
load loss in MV lines	3 627	4 531	2 433	2 372	2 143	2 777

In OSD2 area units the load loss in MV lines has the greatest share in total energy loss, whereas in the case of OSD7, the highest loss occurs in MV/LV transformers. Among all the area units of OSD2, the greatest ratio of technical loss in the LV network to total loss in the network of the unit is attested in RE22 and equals 76,05%, whereas the lowest ratio is in RE12 and equals 47,47%. In the MV network the greatest share in technical loss of a given unit occurs in RE12 and equals 52,53%, whereas the lowest share is in RE22 and equals 23,95%. In the area units within OSD7 the share of technical loss is fairly equally distributed. The highest share of technical loss in the LV network occurs in RE47 and equals 33,57%; whereas the lowest share is in RE77 and equals 26,71%. In the MV network the greatest share in the technical loss is attested in units: RE77 56,30% and RE67 52,53%, while the lowest share is attested in RE27 32,03% and RE57 32,95%.

Table 7 shows mean annual savings obtained by increasing the cross-section of LV and MV lines.

Table 7. Mean annual savings obtained by increasing the cross-section of LV and MV lines

Area unit	60 km of MV lines [MWh]	10% of MV lines [MWh]	60 of LV lines [MWh]	10% of LV lines [MWh]	10% of MV/LV substations [MWh]
RE12	150.06	1 121.3	13.8	122.49	161.40
RE22	13.74	33.04	227.76	1 030	263.87
RE32	162.96	934.67	9.96	212.17	233.81
RE42	125.28	727.20	20.88	166.44	189.43
RE17	843.42	1 918.72	76.26	391.71	672.90
RE27	810.36	2 544.46	80.52	585.10	721.53
RE37	699.00	4 308.27	37.74	371.19	583.81
RE47	233.76	1 261.84	31.74	220.85	338.32
RE57	777.72	1 971.47	79.68	350.33	508.03
RE67	466.80	1 888.94	33.3	193.37	293.31
RE77	364.98	2 211.07	23.70	195.07	319.58

If the volume of the conducting material in MV lines is increased by 2100 km·mm^2 and 60 km of MV lines is modernized, the energy loss will be lowered by 843,42 MWh in RE17 and by 162,96 MWh in RE32. If the volume of the conducting material in LV lines is increased by 1500 km·mm^2 and 60 km of LV lines is modernized, the energy loss will be reduced by 227,76 MWh in RE22, by 80,27 MWh in RE27 and by 79,68 MWh in RE57. If the number of MV/LV substations is increased by 10%, the greatest reduction of energy loss - by 721 MWh - will be obtained in RE27. In RE22 the loss will be lowered by 263,87 MWh.

Table 8 presents unit energy loss reduction per in the particular area units of the distribution company obtained by increasing the volume of the conducting material by 10 km·mm^2 and by adding one MV/LV substation.

Table 8. Mean annual unit energy loss

Area unit	MV network [kWh]	LV network [kWh]	Adding one MV/LV substation [kWh]
RE12	714.44	91.82	519.97
RE22	65.34	1 518.47	2 037.60
RE32	776.08	158.37	864.05
RE42	596.53	139.37	663.98
RE17	4 016.15	508.22	3 773.95
RE27	3 858.75	536.91	2 727.91
RE37	3 328.65	251.74	1 516.01
RE47	1 113.08	211.60	1 457.67
RE57	3 703.34	531.01	2 958.83
RE67	2 222.81	221.94	1 323.01
RE77	1 737.92	158.18	951.98

When the cross-section of 1km of MV and LV lines is increased by 1 mm^2 in OSD2, the greatest loss reduction by 776 kWh will take place in the MV network of RE12. The lowest reduction, only by 65 kWh will occur in RE22. In the LV network the loss will be reduced by 1518 kWh in RE22. In the other area units the loss will be reduced only slightly. Adding one MV/LV substation will benefit RE22 the most, reducing the loss by 2038 kWh per year. In OSD7, increasing the cross-section of 1km MV and LV lines by 1 mm^2 will result in reducing the loss by 4016 kWh in the MV network of R17 and by 3859 kWh in RE27. The smallest loss reduction, equal to 1113 kWh will take place in RE47. In the LV network the loss will be lowered by 537 kWh in R27 and by 531 in R57. The greatest loss reduction due to adding one MV/LV substation will occur in RE17, yielding 3774 kWh savings per year.

Economic analysis

An analysis of the effectiveness of the investment was carried out by means of the following methodology [11, 12]:

Simple payback period/time (SPBT). it is defined as a period required to recoup the funds spent on an investment.

Internal Rate of Return (IRR) is another metric for assessing profitability of investments. As a dynamic method, IRR represents a real return on investment. Based on the discounted cash flow, it takes into account changes in the value of assets in time. The interpretation of IRR is quite simple: the higher the value of IRR, the more profitable an investment will be.

NPV is the most important metric, which represents the difference between the present value of cash inflows and the present value of cash outflows. It can also be defined as surplus of present net profit over an alternative profit obtained from an investment the IRR of which is equal to the discount rate.

The following was assumed in the calculations: the cost of building1 km of 110 kV overhead line 447,000 PLN, the cost of building1 km of MV overhead line 184,000 PLN and of 1 km cable line 176,000 PLN, the cost of building1 km of LV overhead line 103,000 PLN, of 1 km LV cable line 120,000 PLN, the cost of building a MV/LV station – a pole-mount 27,000 PLN, a pad-mount 136,000 PLN, the cost of balance loss 178 PLN/MWh, depreciation rate 4%, the cost of building MV and LV lines, and MV/LV substations were calculated as weighed arithmetic means, with lengths of overhead and cable lines used as weighs, increase in energy per year 1%, time period for which the calculations were carried out 25 years, discount rate 3.9%, net profit was assumed as the worth of energy loss reduction, the cost of replacing a single-phase meter 43 PLN, replacing a three-phase meter 56 PLN, the cost of a single-phase static meter 49 PLN, a three-phase static meter 105 PLN, depreciation rate for meters 12.5%, time period 8 years.

The profitability assessment was carried out for the following cases: increasing the cross-section of the 110 kV line by 120 mm^2 per 1 km on average, increasing the cross-section of the MV line by 35 mm^2 per 1 km on average, increasing the cross-section of the LV line by 25 mm^2 per 1 km on average, increasing the number of MV/LV substations by 10%, increasing the length of LV lines by 10%, replacing induction meters by static meters, replacing all MV/LV transformers produced before 1975 by modern transformers. Table 9 presents the profitability analysis of the investment in the area units.

Table 9. Profitability of the investment in the area units

OSD	1	2	3	4	5	6	7	8
50 km of 110 kV lines								
IRR	0.71	1.09	2.89	1.38	1.45	-0.97	1.54	0.41
NPV	-1.4	-1.2	-0.5	-1.1	-1.1	-2.5	-1.0	-1.49
SPBT	22.8	21.8	18.1	21.0	20.8	22.2	20.6	23.7
10% of LV lines								
IRR	0.23	0.69	2.00	0.48	0.41	0.49	-0.2	0.24
NPV	-82	-62	-16	-74	-87	-83	-112	-59
SPBT	24.4	23.4	20.4	24.2	23.9	24.2	24.2	24.4
10% of MV lines								
IRR	0.67	0.7	1.33	1.59	0.94	1.23	1.52	0.44
NPV	-110	-72	-18	-63	-75	-77	-75	-77
SPBT	23.4	23.0	21.9	21.7	22.7	22.9	20.5	23.9
10% of MV/LV substations								
IRR	1.16	0.75	7.74	1.83	2.58	1.91	1.43	1.12
NPV	-14.8	-11.2	6.2	-9.4	-5.8	-10.1	-15.7	-9.1
SPBT	21.9	22.7	11.3	20.7	18.7	20.7	20.3	21.9
Replacing meters								
IRR	-0.4	-4.2	-2.8	-0.8	-1	-0.1	-0.9	-0.3
NPV	-11	-19	-6	-8	-16	-19	-17	-9
SPBT	12.8	6.8	9.7	13.4	13.8	12.5	13.6	6.3
Replacing transformers								
IRR	3.6	4.25	8.87	1.67	4.33	2.8	2.93	1.91
NPV	-1.5	0.6	0.3	-9.4	0.4	-2.3	-2.0	-3.2
SPBT	22.1	20.2	10.2	25.1	19.9	20.3	19.9	24.3

Replacing transformers produced before the year 1975 by modern ones id the most profitable in OSD3, with the gain of 8.87%, in OSD2, with the gain of 4.25 and in OSD5, with the gain of 4.33. In the other units it is also beneficial, with the gain about 2%. Increasing the number of MV/LV transformer substations will yield the return of 7.74% in OSD3. Also in this unit, increasing the cross-section by 120 mm^2 per each kilometer of the 50 km of the 110 kV line will yield the return of 2.89% after 20 years. Increasing the cross-section of 10% of the MV lines by 35 mm^2 in OSD5 yields a 2.5% return on investment. Replacing induction meters by static meters will not be profitable due to high cost of such a replacement and short life of the meters.

Table10 presents the profitability analysis of investment projects in the OSD2 and OSD7. Three cases are taken into account: 1) increasing the cross-section of MV lines by 35 mm^2 per1 km MV on verage, at the same time increasing the length of MV lines by 10%; 2) increasing the cross-section of LV lines by 25 mm^2 per 1 km, at the same time increasing the length of LV lines by 10%, 3) increasing the number of MV/LV substations by 10%. The profitability of the other projects, i.e. replacing meters and MV/LV transformers will be similar in the companies and area units.

Table 10. Profitability assessment of investment projects in the area units

Area unit	Project	IRR [%]	NPV [PLN]	SPBT [years]
RE12	LV lines	0.17%	-20 062 520	24.68
	MV lines	0.03%	-29 306 842	24.05
	MV/LV station	0.29%	-3 900 005	23.53
RE22	LV lines	1.92%	-6 476 815	20.61
	MV lines	**4.03%**	**371 801**	16.76
	MV/LV station	0.32%	-2 385 266	20.08
RE32	LV lines	0.75%	-17 776 933	23.17
	MV lines	0.02%	-23 059 073	24.94
	MV/LV station	0.78%	-3 031 361	22.64
RE42	LV lines	0.37%	-17 594 944	24.55
	MV lines	0.61%	-20 206 024	23.46
	MV/LV station	0.53%	-3 401 794	23.15
RE17	LV lines	0.29%	-11 365 369	23.76
	MV lines	3.06%	-2 234 797	18.59
	MV/LV station	3.33%	-396 912	17.19
RE27	LV lines	-0.08%	-17 008 875	23.70
	MV lines	2.68%	-4 327 705	18.78
	MV/LV station	2.15%	-1 688 586	18.82
RE37	LV lines	-0.63%	-24 232 462	24.35
	MV lines	1.86%	-13 310 338	19.48
	MV/LV station	0.73%	-4 123 864	21.14
RE47	LV lines	-0.33%	-16 574 055	24.45
	MV lines	0.12%	-20 128 948	22.84
	MV/LV station	1.08%	-2 317 092	21.27
RE57	LV lines	0.53%	-9 289 645	23.70
	MV lines	2.76%	-3 316 792	18.96
	MV/LV station	2.70%	-789 924	18.43
RE67	LV lines	-0.12%	-13 597 717	24.43
	MV lines	1.27%	-11 230 229	21.02
	MV/LV station	0.99%	-2 280 752	21.57
RE77	LV lines	-0.57%	-20 243 381	24.59
	MV lines	0.58%	-20 157 716	21.78
	MV/LV station	0.23%	-4 105 160	22.43

As can be seen, increasing the cross-section of MV lines is generally ineffective in OSD2, but it turns out to be profitable for RE22, with the profit reaching 4.03%. In RE17 increasing the MV lines cross-section by 35 mm^2 per km will yield the profit of 3.06%. In RE57 the profit will be 2.76% and in RE27 2.68%. The profit for OSD1 will be 1.52%. In RE17, increasing the number of MV/LV substations by 10% will yield 3.33% profit after 25 years, whereas this project is unprofitable for RE77. The profit for the whole OSD7 is 1.43%.

Concluding remarks

- The greatest percentage of energy loss is constituted by load loss in MV lines as well as loss in MV/LV transformers. Increasing the cross-section of MV lines and increasing the number of MV/LV substations contributes the greatest reduction of energy loss. The exact level of loss reduction varies significantly from one OSD to another.
- Since the area covered by distribution companies is large, it is advisable to carry out profitability analysis for smaller areas, such as particular units of distribution companies. In this was the analysis will be more detailed and the investment funds will be spent more effectively.
- In the LV network the greatest loss reduction will be obtained by increasing the number of MV/LV substations.
- The most profitable action is replacing high-loss MV/LV transformers by low-loss ones. Special attention needs to be paid to the optimal selection of the transformer load coefficient.
- Due to short period of exploitation, it is not beneficial to replace induction meters by static ones.

***Author**: dr hab. inż. Anna Gawlak, Politechnika Częstochowska, Instytut Elektroenergetyki, ul. Dąbrowskiego 69, 42-200 Częstochowa, E-mail: gawlak@el.pcz.czest.pl.*

REFERENCES

[1] Gawlak A., The Influence of Investment on Reducing Energy Losses in Distribution Networks, *in Proc. 16th International Scientific Conference on Electric Power Engineering*, (2015), 315-319
[2] Kornatka M., The weighted kernel density estimation methods for analysing reliability of electricity supply, in *Proc. 17th International Scientific Conference on Electric Power Engineering,* (2016), 2-5
[3] Gawlak A., Podział środków inwestycyjnych na rozwój sieci rozdzielczych przy zastosowaniu metody taksonomicznej, *Przegląd Elektrotechniczny*, R.85 nr 3 (2009), 157-160
[4] Witryna internetowa www.ptpiree.pl/examples/raport_2018 (dostęp: 2018.10.14)
[5] Gawlak A., Noninvestment Forms of Reducing Energy Losses in Distribution Networks, *in Proc. 8th International Scientific Symposium on Electrical Power Engineering*, (2015), 61-64
[6] Kornatka A., and Gawlak A., Comparative Analysis of Operating Conditions in Polish Medium-voltage and 110 kV Networks, *in Proc. 8th International Scientific Symposium on Electrical Power Engineering*, (2015), 57-60
[7] Gawlak A., Analysis of technical losses in the low and medium voltage power network, *in Proc. 11 th International Scientific Conference on Electrical Power Enginering,* (2010), 119-123
[8] Kolcun M., Kornatka M., Gawlak A., and Čonka Z., Benchmarking the reliability of medium-voltage lines, *Journal of Electrical Engineering* vol. 68 (3), (2017), 212-215
[9] Gawlak A., Technological aspects of electrical energy distribution, *in Proc. 14th International Scientific Conferenc Electric Power Engineering,* (2014), 45-48
[10] Goňo M., Kyncl M., Goňo R., Kłosok-Bazan I., Experience with the production of electricity from biogas at sewage treatment plant in the Czech Republic, *Przegląd Elektrotechniczny*, Volume 89, Issue 11, (2013), 12-15
[10] Sowiński J., Comparison of RAINS and Fisher's models for calculating sulphur deposition in Poland, Atmospheric Environment Vol.29, No.22, 1995), 3385-3389
[11] Paska J., Ekonomika w elektroenergetyce, *Oficyna Wydawnicza Politechniki Warszawskiej*, (2007)
[12] Gawlak A., Kierunki inwestowania a straty energii elektrycznej w sieci rozdzielczej, *Przegląd Elektrotechniczny*, R.93 nr 3 (2017), 40-43.