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Profitability of investment in power distribution industry

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Abstract. Striving towards improving efficiency in the power sector puts an obligation on distribution companies to seek ways of reducing electricity loss. The highest energy loss in the distribution network is attested in electricity meters, in LV and MV lines and in MV/LV transformers. The paper analyses effectiveness of investment aimed to reduce energy loss in a distribution company. The analysis is carried out with the use of SPBP, IRR and NPV.

1 Introduction

Power industry provides a foundation and a driving force for all economic activities and development. Its role was first recognized during the industrial revolution and has been increasing ever since. Nowadays, no society can function without continuous energy supply. Considering this, it has to be acknowledged that the methodology for analyzing the cost of energy generation and distribution, including the influence of all variables, is of essential importance for planning the future of the power system.

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.

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. The main factors responsible for the investment in the distribution sector include [1-3]:

- condition of technological equipment,
- EU requirements concerning energy loss in transmission,
- the project of implementing smart grids.

The necessity of making for 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. The directions of development for the distribution network are as follows [4-8]:

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- reducing energy loss in distribution transformers and networks. The necessity to use high-efficiency transformers follows from the general tendency to reduce loss occurring at the stage of energy transmission and distribution and is also stipulated by the Commission Regulation (EU) No 548/2014 of 21 May 2014 on implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to small, medium and large power transformers, which sets a limit on the maximal level of idle and load loss in newly installed distribution transformers,
- modernizing and expanding the 110 kV distribution network and networks of lower voltages with a view to the following:
  - minimizing technical and accounting loss by introducing new telemetric solutions,
  - increasing reliability by optimizing network configuration and reducing the length of overhead lines,
  - expanding the network in order to offer services to a greater number of customers,
  - connecting renewable energy sources, even if they are challenging to manage.

2 Reducing energy loss by investment

The study was carried out on the basis of data obtained from a distribution company covering 8 area units (OSD). The data concerned the amount of energy flowing through the particular voltage levels and the number of distribution devices. Losses were calculated by means of the program EUROEFEKT, as presented in Table 1.

Table 1. Energy loss in the distribution network [MWh].

Loss	OSD1	OSD2	OSD3	OSD4	OSD5	OSD6	OSD7	OSD8
in meters	9863	10360	5593	9187	13532	15478	16036	9504
load loss in LV lines	20439	9334	40244	23002	31533	25270	37812	11405
idle in MV/LV transformers	37351	30142	16957	26341	34060	37269	50392	20502
load loss in MV/LV transf.	8885	4072	11166	8202	7890	11581	21434	4095
commercial/unit [kWh/cons./year]	63.27	94.37	68.14	62.03	77.94	139.8	139.8	72.65
other tech. in LV	6974	4501	5042	6159	6711	6884	11391	3756
load loss in MV lines	76475	36085	89495	101212	58654	80128	183451	30571
other tech. in MV	7115	6731	5196	4691	7372	5822	6947	4042
load loss in 110 kV lines	26529	31269	33174	55222	63486	35166	55190	13553
in110/MV transformers	24343	19805	20290	26930	20098	19670	40810	11747

Commercial loss constitutes from 13% to 31% of total balance loss in particular units, the mean being 91 kWh/consumer/year. It is not a high value, especially considering the fact that it includes the system-related loss component, the exact value of which is not known due to lack of current data. It is estimated though that the system-related accounting loss component is about 60 kWh/consumer/year for induction meters and about 30 kWh/consumer/year for static meters. Since there are about 50% of static meters in area units, the system-related accounting loss can be estimated at the level of 45 kWh/consumer/year. The highest level of illegal energy consumption occurs in OSD 7. The main component of total loss, however, is load loss in MV lines, amounting to 33.81% in OSD 3 and to 17.24% in OSD 2. The MV/LV transformer loss is also high – the highest share is 17.43% of total balance loss in OSD 1 and the lowest 10.63% in OSD 3. The latter unit is also characterized by the most advantageous ratio of idle loss to load loss, which indicates that the transformer power is selected adequately to the level of energy flow. 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 stations,
- 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 2 includes technical parameters of networks in the particular area units.

Table 2. Mean cross-section and length of the network lines.

	Length of 110 kV lines [km]	mean cross-section of 110 [mm^2]	mean length of MV lines [km]	mean cross-section of MV [mm^2]	mean length of LV lines [m]	mean cross-section of LV [mm^2]	number of MV/LV stations
OSD1	1495	226.04	26.8	48.11	446.22	42.95	14679
OSD2	1045	241.96	22.87	49.30	504.49	42.05	9885
OSD3	397	263.81	16.57	48.82	437.52	46.97	3647
OSD4	1311	248.76	32.87	42.20	614.75	41.8	11866
OSD5	1789	213.49	23.73	47.67	514.59	46.61	11433
OSD6	1606	207.19	26.19	45.71	556.98	45.98	13139
OSD7	1478	210.50	25.88	46.67	527.14	48.82	17777
OSD8	1055	207.14	27.77	48.55	575.00	41.76	8985

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. For example, 1 km of a line with the cross-section 120 mm^2 can be replaced by 1 km of a line with the cross-section 240 mm^2.
- 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. For example, 1 km of a line with the cross-section 35 mm^2 can be replaced by 1 km of a line with the cross-section 70 mm^2.

- 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. For example, 1 km of a line with the cross-section 25 mm^2 can be replaced by 1 km of a line with the cross-section 50 mm^2.

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[toe]	10% of 110 kV line[toe]	60 km of MV line [toe]	10% of MV line [toe]	60 km of LV line[toe]	10% of LV line [toe]
OSD1	8.14	121.67	15.73	528.22	3.33	107.85
OSD2	12.81	133.85	9.72	242.15	6.15	131.64
OSD3	32.82	130.30	9.95	194.86	4.82	360.58
OSD4	16.30	213.66	33.46	786.05	4.10	143.61
OSD5	17.26	308.74	21.67	365.47	5.22	188.59
OSD6	10.92	175.34	20.64	514.48	4.24	165.64
OSD7	18.39	271.82	51.54	1384.76	4.46	198.42
OSD8	4.65	49.02	10.01	205.09	3.02	79.03

As it can be seen in Table 3, the greatest savings can be obtained in OSD3 – 3.82 toe per each kilometer of the 110 kV line. The lowest savings at the level of 0.47 toe 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 51.54 toe 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 3.02 toe, and the greatest, equal to 6.15 toe will be obtained in OSD2.

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

Area unit	Replacing induction meters by static meters [toe]	Increasing the number of MV/LV stations by 10% [toe]	Replacing old transformers by new ones [toe]	Reducing the power of existing transformers by 10% [toe]
OSD1	418.61	159.76	526.09	146.11
OSD2	571.31	72.96	220.90	151.28
OSD3	329.89	314.57	11.97	-10.51
OSD4	268.46	179.78	156.56	82.24
OSD5	468.11	278.09	116.60	159.03
OSD6	789.96	197.53	319.74	116.53
OSD7	499.06	295.57	321.62	95.34
OSD8	477.67	89.15	167.82	88.62

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 stations by 10% will contribute to saving 315 and 296 toe in OSD3 and OSD7, respectively. If all transformers manufactured before 1975 are replaced, the greatest savings will be obtained in OSD1 – 526 toe and the smallest in OSD3 – 12 toe. Lowering the power of existing transformers and increasing their load by 10% will yield the savings in the final energy output of 159 toe in OSD5 and of 151 toe w 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 unit the transformer power is selected optimally with respect to the network load.

Table 5 presents the results of energy loss reduction in the particular units, obtained by increasing the volume of the conducting material by 10 km·mm^2 and adding one MV/LV transformer station.

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

Area unit	110 kV network [toe]	MV network [toe]	LV network [toe]	Adding one MV/LV station [toe]
OSD1	0.068	0.075	0.022	0.138
OSD2	0.107	0.046	0.041	0.088
OSD3	0.274	0.047	0.032	0.861
OSD4	0.136	0.159	0.027	0.150
OSD5	0.144	0.075	0.035	0.254
OSD6	0.091	0.098	0.028	0.151
OSD7	0.153	0.245	0.030	0.181
OSD8	0.039	0.048	0.020	0.100

The highest mean savings per year at the level of 0.274 toe in the 110 kV network will be obtained in OSD3, whereas in OSD7 in the MV network the amount of energy saved will be 0.245 toe. The lowest savings of 0.02 toe 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 0.861 toe of energy. In OSD2 and OSD8 this effect will be much less conspicuous – only 0.088 toe and 0.1 toe of energy saved, respectively.

3 Economic analysis

An analysis of the effectiveness of the investment was carried out by means of the following methodology [9]:

Simple payback period/time (SPBP, SPBT) is the most often applied static criterion for assessing efficiency of investment. It is defined as a period required to recoup the funds spent on an investment. It is calculated from the time of launching an investment until the break-even point, i.e. when the return has paid for the invested funds.

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. IRR can also be defined as a discount rate for which the Net Present Value (NPV) is equal to zero (NPV=0). IRR then stands for a rate for which a threshold of profitability is reached when the present value of outflowing cash is equal to inflowing cash.

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 stations 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 for which the calculations were carried out in the case of meters 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, adding 50 km of the 110 kV line,
- increasing the cross-section of the MV line by 35 mm^2 per 1 km on average, adding 10% of the MV line,
- increasing the cross-section of the LV line by 25 mm^2 per 1 km on average,
- increasing the number of MV/LV stations 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,
- replacing some of the existing transformers, with the cost of investment assumed as the cost of purchasing 10% of transformers with respect to the current number. For each newly purchased transformer, four will be replaced. The cost of replacing one transformer is estimated as 2,000 PLN.

Table 6 presents the profitability analysis of the investment in the area units.

Table 6. Profitability of the investment in the area units.

	OSD1	OSD2	OSD3	OSD4	OSD5	OSD6	OSD7	OSD8
50 km of 110 kV lines								
IRR [%]	0.71	1.09	2.89	1.38	1.45	-0.97	1.54	0.41
NPV [m. PLN]	-1.4	-1.2	-0.5	-1.1	-1.1	-2.5	-1.0	-1.49
SPBT [years]	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 [thousand PLN]	-82	-62	-16	-74	-87	-83	-112	-59
SPBT [years]	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 [m. PLN]	-110	-72	-18	-63	-75	-77	-75	-77
SPBT[years]	23.4	23.0	21.9	21.7	22.7	22.9	20.5	23.9
10% of MV/LV stations								
IRR [%]	1.16	0.75	7.74	1.83	2.58	1.91	1.43	1.12
NPV [m. PLN]	-14.8	-11.2	6.2	-9.4	-5.8	-10.1	-15.7	-9.1
SPBT [years]	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 [m. PLN]	-11	-19	-6	-8	-16	-19	-17	-9
SPBT [lata]	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 [m. PLN]	-1.5	0.6	0.3	-9.4	0.4	-2.3	-2.0	-3.2
SPBT [years]	22.1	20.2	10.2	25.1	19.9	20.3	19.9	24.3
Increasing the load by 10% in MV/LV transformers								
IRR [%]	-1.2	0.2	-0.6	-8.6	-1.0	-3.6	-4.9	-2.6
NPV [m. PLN]	-13	-7	-5	-19	-10	-14	-21	-9
SPBT [years]	19.2	17.1	27.4	18.7	18.4	19.7	21.5	19.2

Replacing transformers produced before the year 1975 by modern ones is 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%. In the case of replacing transformers, the magnitude of the gain depends on mean power and load coefficients in transformers produced before 1975.

Increasing the number of MV/LV transformer stations 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. Increasing the load coefficient of transformers will not yield any return either. It was assumed that for each newly purchased MV/LV transformer, four other transformers will be replaced by ones with power adequately selected with respect to load. Since the cost of purchasing a new transformer is high, such an investment will not yield a return. On the other hand, other actions that do not require investment or incur cost should be taken to ensure that the load of transformers is economically justifiable.

4 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 stations contributes the greatest reduction of energy loss. The exact level of loss reduction varies significantly from one OSD to another.

The analysis of the distribution network offered in this paper took into account only reducing losses of electric energy and the calculations were based on mean values. Therefore, even though the analysis may indicate that a given OSD on the whole will get little benefit from investment, there may be particular lines within this OSD in which increasing the cross-section may yield large energy savings.

In the LV network the greatest loss reduction will be obtained by increasing the number of MV/LV stations. The effect of adding new MV/LV stations will be the most beneficial for OSD3.

Increasing the cross-section of lines in the LV network will bring about loss reduction too, but the effect will be much smaller than that achieved by increasing the number of MV/LV stations.

The most profitable action is replacing high-loss MV/LV transformers by low-loss ones. Due to short period of exploitation, it is not beneficial to replace induction meters by static ones.

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