Power System Planning: Part II—Practical Applications

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Abstract. Power system planning is an activity related to the development of plans for designing and construction of the system and its elements, which will satisfy assumed future needs, starting from the given state. First paper presents basic principles of power system development planning with its concepts. Electrical energy losses as well as forecasting of energy consumption are taken in consideration. Basic principles of development planning for each subsystem (generation, transmission and distribution) are presented. In the second paper, practical application of techno-economic analysis of the transition from the voltage level of 10–20 kV in Gračanica is presented with two different investment costs using four different approaches.

1 Introduction

Power system planning is an area where technology and economics must be interconnected. The construction of new electric power facilities and their exploitation are closely related to the costs and revenues of the owners (companies). In power system development planning process, the engineering economy methods are being used for systematic analyzes and estimation of costs and revenues, resulting from various system development projects in the future.

This paper presents a techno-economic analysis with cost effectiveness of the transition from the voltage level of 10–20 kV in Gračanica . Two cases have been observed:

- investment costs of 2 500 000,00 km (from now on Case 1)
- investment costs of 3 600 000,00 km (from now on Case 2).

It is important to note that for the Case 1 investment costs are reffered to replacement of the power system elements that are not capable to work on 20 kV voltage level only. Thus, certain number of elements will not be replaced.

On the other hand, in Case 2 all elements will be replaced with the new one that can operate on voltage level 20 kV.

In this paper four methods are used for economic appraisal of a project, namely as:

- Rate of Return Method;
- Net Present Value;
- Internal Rate of Return Method;

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- Profitability Index Method [1].

The aim of the paper was to check the cost-effectiveness of transition from the voltage level of 10 kV to voltage level of 20 kV.

2 Current State of Distribution Network Gračanica

Table 1 shows technical parameters of distribution network Gračanica for voltage level 10 kV as well as the voltage level 20 kV.

Difference in losses (ΔW) while using 10 kV voltage level comparing with voltage level 20 kVs equals 2.552, 37 MWh/year.

Since the price of 1 kWh amounts 0.15 km total annual profit can be calculated as:

$$2552370\left[\frac{\text{KWh}}{\text{year}}\right] \times 0{,}15\left[\frac{\text{KM}}{\text{KWh}}\right] = 382855{,}5[\text{KM/year}] \tag{1}$$

3 Rate of Return Method

The problem of selecting a project realization can be seen from the aspect of the time the funds will be repaid.

This time period of return is defined as the number of years for which the savings on the exploitation costs are equal to the investment costs. The project is more profitable as the time of investments return is less [3, 4].

The total investment costs of transition from 10 to 20 kV is 2 500 000,00 km in the first case and 3 600 000,00 km in the second one.

Expected revenues for the first 15 years for Case 1 are given in Table 2.

Expected revenues for the first 15 years for Case 2 are given in Table 3.

The time (or deadline) of return on invested costs represents the time when the total amount of money invested in the realization of the project is returned from the pure income of the economic flow. The criterion of project rating according to this indicator is actually the length of the return period. Shorter time means that the project is more acceptable.

The return period is calculated as the ratio of the initial investment costs and the annual cash flow revenue of the project [5].

From the previous analysis cost effectiveness of the project would be 7 years in Case 1 and 10 years in Case 2 resulting from the project conditions as shown in Figs. 1 and 2.

4 Net Present Value

Net present value represents the fundamental criteria of financial decision-making. All cash flows are reduced to their present value.

In general case:

Table 1. Technical parameters of the distribution network Gračanica TS 10(20) kV/0.4 kV [2]

Losses										
Pmax [kW]	10 kV			20 kV			Ukupno		T [h]	ΔW [MWh/year]
	Ploss [kW]	Ploss [%]	P0 [kW]	Ploss [kW]	Ploss [%]	P0 [kW]	ΔPloss [kW]	ΔPloss [kW]		
311,50	0,03	0,01	0,00	0,01	0,00	0,00	0,02	0,01	2.400	0,02
2.327,00	256,70	11,03	11,09	84,51	3,63	10,16	172,19	7,40	4.083	397,53
518,10	6,44	1,24	14,73	3,81	0,74	1,57	2,63	0,51	5.557	74,54
1.870,00	92,41	4,94	10,67	39,65	2,12	10,35	52,76	2,82	4.693	154,07
21,98	0,91	4,13	23,54	0,87	3,94	0,85	0,04	0,19	4.376	140,80
1.695,00	75,78	4,47	13,94	33,15	1,96	12,81	42,63	2,52	4.929	140,20
2.332,00	69,45	2,98	18,46	33,02	1,42	17,70	36,43	1,56	5.883	159,30
1.603,00	268,50	16,75	12,93	69,90	4,36	10,86	198,60	12,39	4.651	576,33
1.701,00	154,90	9,11	9,91	57,95	3,41	9,64	96,95	5,70	5.090	323,37
1.643,00	30,38	1,85	11,11	20,84	1,27	11,09	9,54	0,58	5.436	35,63
3.229,00	69,88	2,16	9,96	29,93	0,93	9,87	39,95	1,24	4.639	113,49
1.698,00	215,50	12,69	14,25	63,22	3,72	12,36	152,28	8,97	4.609	437,09
18.949,58	1.240,87	6,55	150,59	436,85	2,31	107,26	804,02	4,24		2.552,37

Table 2. Expected revenues for the next 15 years (Case 1)

Project year	Year	Total investments	Net income (annual amount)	Cumulative net income
0	2018	2500000	−2500000	−2500000
1	2019		382855,5	−2117144,5
2	2020		382855,5	−1734289
3	2021		382855,5	−1351433,5
4	2022		382855,5	−968578
5	2023		382855,5	−585722,5
6	2024		382855,5	−202867
7	2025		382855,5	179988,5
8	2026		382855,5	562844
9	2027		382855,5	945699,5
10	2028		382855,5	1328555
11	2029		382855,5	1711410,5
12	2030		382855,5	2094266
13	2031		382855,5	2477121,5
14	2032		382855,5	2859977

Table 3. Expected revenues for the next 15 years (Case 2)

Project year	Year	Total investments	Net income (annual amount)	Cumulative net income
0	2018	3600000	−3600000	−3600000
1	2019		382855,5	−3217144,5
2	2020		382855,5	−2834289
3	2021		382855,5	−2451433,5
4	2022		382855,5	−2068578
5	2023		382855,5	−1685722,5
6	2024		382855,5	−1302867
7	2025		382855,5	−920011,5
8	2026		382855,5	−537156
9	2027		382855,5	−154300,5
10	2028		382855,5	228555
11	2029		382855,5	611410,5
12	2030		382855,5	994266
13	2031		382855,5	1377121,5
14	2032		382855,5	1759977

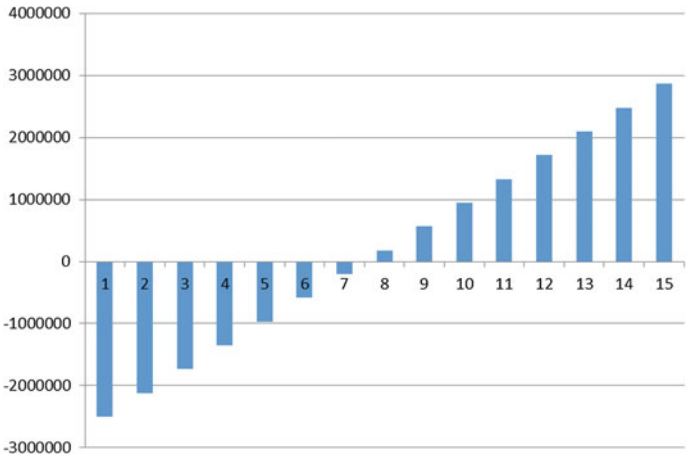

Fig. 1. Profit per years (Case 1)

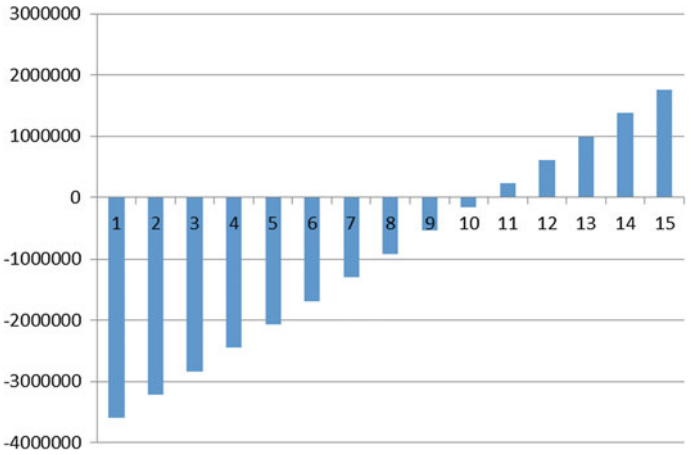

Fig. 2. Profit per years (Case 2)

$$S_0 = \sum_{t=1}^{T} \frac{V_t}{(1+k)^t} - I_0 \tag{2}$$

$$S_0 = \sum_{t=1}^{T} \frac{(P_t - Z_t)}{(1+k)^t} - I_0 \tag{3}$$

where

I_0 investment costs;
P_t annual revenue;
Z_t annual expenses [5].

Table 4. Discount factor, discount rate and annual net income for Case 1

Discount factor									
Project year	Net income (annual amount)	4	6	8	10	12	14	16	Discount rate
0	−2500000								
1	382855,5	0,962	0,943	0,926	0,909	0,893	0,877	0,862	
2	382855,5	0,925	0,890	0,857	0,826	0,797	0,769	0,743	
3	382855,5	0,889	0,840	0,794	0,751	0,712	0,675	0,641	
4	382855,5	0,855	0,792	0,735	0,683	0,636	0,592	0,552	
5	382855,5	0,822	0,747	0,681	0,621	0,567	0,519	0,476	
6	382855,5	0,790	0,705	0,630	0,564	0,507	0,456	0,410	
7	382855,5	0,760	0,665	0,583	0,513	0,452	0,400	0,354	
8	382855,5	0,731	0,627	0,540	0,467	0,404	0,351	0,305	
9	382855,5	0,703	0,592	0,500	0,424	0,361	0,308	0,263	
10	382855,5	0,676	0,558	0,463	0,386	0,322	0,270	0,227	
11	382855,5	0,650	0,527	0,429	0,350	0,287	0,237	0,195	
12	382855,5	0,625	0,497	0,397	0,319	0,257	0,208	0,168	
13	382855,5	0,601	0,469	0,368	0,290	0,229	0,182	0,145	
14	382855,5	0,577	0,442	0,340	0,263	0,205	0,160	0,125	

Table 5. Discount factor, discount rate and annual net income for Case 2

Discount factor									
Project year	Net income (annual amount)	4	6	8	10	12	14	16	Discount rate
0	−3600000								
1	382855,5	0,962	0,943	0,926	0,909	0,893	0,877	0,862	
2	382855,5	0,925	0,890	0,857	0,826	0,797	0,769	0,743	
3	382855,5	0,889	0,840	0,794	0,751	0,712	0,675	0,641	
4	382855,5	0,855	0,792	0,735	0,683	0,636	0,592	0,552	
5	382855,5	0,822	0,747	0,681	0,621	0,567	0,519	0,476	
6	382855,5	0,790	0,705	0,630	0,564	0,507	0,456	0,410	
7	382855,5	0,760	0,665	0,583	0,513	0,452	0,400	0,354	
8	382855,5	0,731	0,627	0,540	0,467	0,404	0,351	0,305	
9	382855,5	0,703	0,592	0,500	0,424	0,361	0,308	0,263	
10	382855,5	0,676	0,558	0,463	0,386	0,322	0,270	0,227	
11	382855,5	0,650	0,527	0,429	0,350	0,287	0,237	0,195	
12	382855,5	0,625	0,497	0,397	0,319	0,257	0,208	0,168	
13	382855,5	0,601	0,469	0,368	0,290	0,229	0,182	0,145	
14	382855,5	0,577	0,442	0,340	0,263	0,205	0,160	0,125	

Table 6. Net present value method (Case 1)

Discount cash flow								
Project year	4	6	8	10	12	14	16	Discount rate
0	−2500000	−2500000	−2500000	−2500000	−2500000	−2500000	−2500000	
1	368130,3	361184,4	354495,8	348050,5	341835,3	335838,2	330047,8	
2	353971,4	340740	328236,9	316409,5	305210,1	294594,9	284524	
3	340357,1	321452,9	303923	287645	272509	258416,6	245279,3	
4	327266,5	303257,4	281410,2	261495,5	243311,6	226681,2	211447,7	
5	314679,3	286091,9	260565	237723,1	217242,5	198843,1	182282,5	
6	302576,3	269898	241263,9	216111,9	193966,5	174423,8	157140,1	
7	290938,7	254620,8	223392,5	196465,4	173184,4	153003,3	135465,6	
8	279748,8	240208,3	206844,9	178604,9	154628,9	134213,5	116780,7	
9	268989,2	226611,6	191523,1	162368,1	138061,5	117731,1	100673	
10	258643,5	213784,5	177336,2	147607,4	123269,2	103272,9	86787,06	
11	248695,6	201683,5	164200,2	134188,5	110061,8	90590,26	74816,43	
12	239130,4	190267,5	152037,2	121989,6	98269,47	79465,14	64496,93	
13	229933,1	179497,6	140775,2	110899,6	87740,6	69706,27	55600,8	
14	221089,5	169337,4	130347,4	100817,8	78339,82	61145,85	47931,72	
S0	1544150	1058636	656351,5	320376,8	37630,66	-202074	-406726	

Table 7. Net present value method (Case 2)

Discount cash flow								
Project year	4	6	8	10	12	14	16	Discount rate
0	−3600000	−3600000	−3600000	−3600000	−3600000	−3600000	−3600000	
1	368130,3	361184,4	354495,8	348050,5	341835,3	335838,2	330047,8	
2	353971,4	340740	328236,9	316409,5	305210,1	294594,9	284524	
3	340357,1	321452,9	303923	287645	272509	258416,6	245279,3	
4	327266,5	303257,4	281410,2	261495,5	243311,6	226681,2	211447,7	
5	314679,3	286091,9	260565	237723,1	217242,5	198843,1	182282,5	
6	302576,3	269898	241263,9	216111,9	193966,5	174423,8	157140,1	
7	290938,7	254620,8	223392,5	196465,4	173184,4	153003,3	135465,6	
8	279748,8	240208,3	206844,9	178604,9	154628,9	134213,5	116780,7	
9	268989,2	226611,6	191523,1	162368,1	138061,5	117731,1	100673	
10	258643,5	213784,5	177336,2	147607,4	123269,2	103272,9	86787,06	
11	248695,6	201683,5	164200,2	134188,5	110061,8	90590,26	74816,43	
12	239130,4	190267,5	152037,2	121989,6	98269,47	79465,14	64496,93	
13	229933,1	179497,6	140775,2	110899,6	87740,6	69706,27	55600,8	
14	221089,5	169337,4	130347,4	100817,8	78339,82	61145,85	47931,72	
S0	444149,7	−41364,3	−443649	−779623	−1062369	−1302074	−1506726	

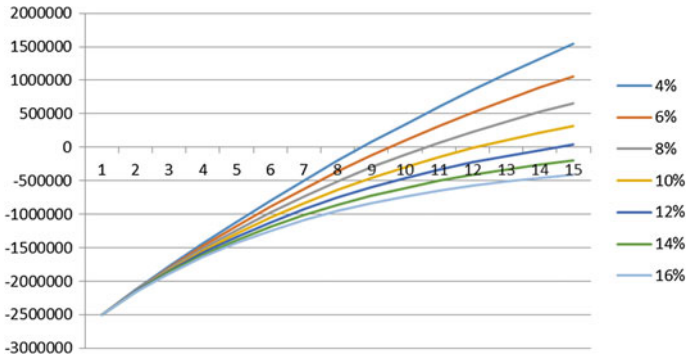

Fig. 3. Time of return of invested costs for different discount rates (Case 1)

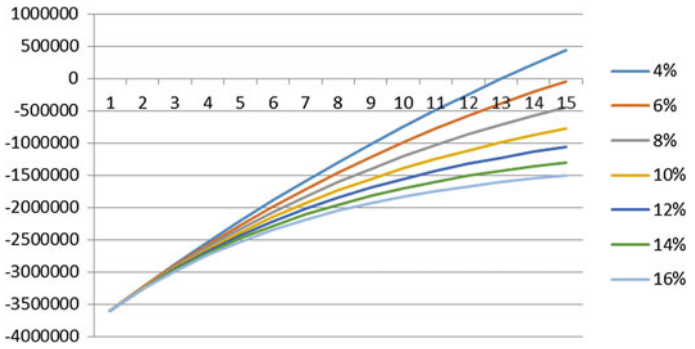

Fig. 4. Time of return of invested costs for different discount rates (Case 2)

Discount factor, discount rate and annual net income for both cases are given in Tables 4 and 5.

After performing calculations, the results of the discount cash flows are shown below in Tables 6 and 7. As a condition for the acceptability of the project is $S_0 \geq 0$, it is clear from the results that this project is profitable for discount rates up to 12% in first case and 4% in the second case.

Net Present Value for different discount rates is presented in Fig. 3 for Case 1 and Fig. 4 for Case 2.

5 Internal Rate of Return Method

Internal rate of return method is also called a method of profit index. The internal rate of return sometime known as yield on project is the rate at which an investment project promises to generate a return during its useful life. It is the discount rate at which the present value of a project's net cash inflows becomes equal to the present value of its

Table 8. Internal rate of return method (Case 1)

Discount cash flow								
Project year	4	6	8	10	12	14	16	Discount rate
0	−2500000	−2500000	−2500000	−2500000	−2500000	−2500000	−2500000	
1	368076,9	361132,1	354444,4	348000	341785,7	335789,5	330000	
2	353920,1	340690,6	328189,3	316363,6	305165,8	294552,2	284482,8	
3	340307,8	321406,3	303879	287603,3	272469,5	258379,1	245243,8	
4	327219	303213,5	281369,4	261457,6	243276,3	226648,3	211417	
5	314633,7	286050,4	260527,2	237688,7	217211	198814,3	182256,1	
6	302532,4	269858,9	241228,9	216080,6	193938,4	174398,5	157117,3	
7	290896,5	254583,9	223360,1	196436,9	173159,3	152981,2	135445,9	
8	279708,2	240173,5	206814,9	178579	154606,5	134194	116763,7	
9	268950,2	226578,7	191495,3	162344,6	138041,5	117714	100658,4	
10	258606	213753,5	177310,5	147586	123251,4	103257,9	86774,48	
11	248659,6	201654,3	164176,4	134169,1	110045,9	90577,13	74805,59	
12	239095,8	190239,9	152015,1	121971,9	98255,23	79453,62	64487,58	
13	229899,8	179471,6	140754,8	110883,5	87727,88	69696,16	55592,74	
14	221057,5	169312,8	130328,5	100803,2	78328,46	61136,98	47924,77	
IRR	7,97%	5,93%	3,97%	2,08%	0,26%	-1,50%	-3,20%	

Table 9. Internal rate of return method (Case 2)

Discount cash flow								
Project year	4	6	8	10	12	14	16	Discout rate
0	−3600000	−3600000	−3600000	−3600000	−3600000	−3600000	−3600000	
1	368076,9	361132,1	354444,4	348000	341785,7	335789,5	330000	
2	353920,1	340690,6	328189,3	316363,6	305165,8	294552,2	284482,8	
3	340307,8	321406,3	303879	287603,3	272469,5	258379,1	245243,8	
4	327219	303213,5	281369,4	261457,6	243276,3	226648,3	211417	
5	314633,7	286050,4	260527,2	237688,7	217211	198814,3	182256,1	
6	302532,4	269858,9	241228,9	216080,6	193938,4	174398,5	157117,3	
7	290896,5	254583,9	223360,1	196436,9	173159,3	152981,2	135445,9	
8	279708,2	240173,5	206814,9	178579	154606,5	134194	116763,7	
9	268950,2	226578,7	191495,3	162344,6	138041,5	117714	100658,4	
10	258606	213753,5	177310,5	147586	123251,4	103257,9	86774,48	
11	248659,6	201654,3	164176,4	134169,1	110045,9	90577,13	74805,59	
12	239095,8	190239,9	152015,1	121971,9	98255,23	79453,62	64487,58	
13	229899,8	179471,6	140754,8	110883,5	87727,88	69696,16	55592,74	
14	221057,5	169312,8	130328,5	100803,2	78328,46	61136,98	47924,77	
IRR	1,74%	-0,18%	−2,03%	−3,81%	−5,53%	−7,18%	−8,78%	

net cash outflows. In other words, internal rate of return is the discount rate at which a project's net present value becomes equal to zero [6].

Formula of internal rate of return factor:

$$IRR = \frac{net\ initial\ investment}{annual\ cash\ inflow} \tag{4}$$

Results of the IRR calculation for both cases are presented in Tables 8 and 9.

6 Profitability Index Method

The Profitability Index Method is an extension of the Net Present Value Method. It provides comparative profitability among different investments by dividing the present value of future cash flows by a project's initial investment [6].

It represents an additional criterion in decision making and takes into account the time value of money:

$$P_I = \frac{\sum_{t=1}^{T} \frac{V_t}{(1+k)^t}}{I_0} \tag{5}$$

Selection criterion: $P_I > 1, \max P_I$

Results of the PI calculations are given in Tables 10 and 11 for two different investments costs [5].

Table 10. Profitability index method (Case 1)

Discount rate	4	6	8	10	12	14	16
	368076,9	361132,1	354444,4	348000	341785,7	335789,5	330000
	353920,1	340690,6	328189,3	316363,6	305165,8	294552,2	284482,8
	340307,8	321406,3	303879	287603,3	272469,5	258379,1	245243,8
	327219	303213,5	281369,4	261457,6	243276,3	226648,3	211417
	314633,7	286050,4	260527,2	237688,7	217211	198814,3	182256,1
	302532,4	269858,9	241228,9	216080,6	193938,4	174398,5	157117,3
	290896,5	254583,9	223360,1	196436,9	173159,3	152981,2	135445,9
	279708,2	240173,5	206814,9	178579	154606,5	134194	116763,7
	268950,2	226578,7	191495,3	162344,6	138041,5	117714	100658,4
	258606	213753,5	177310,5	147586	123251,4	103257,9	86774,48
	248659,6	201654,3	164176,4	134169,1	110045,9	90577,13	74805,59
	239095,8	190239,9	152015,1	121971,9	98255,23	79453,62	64487,58
	229899,8	179471,6	140754,8	110883,5	87727,88	69696,16	55592,74
	221057,5	169312,8	130328,5	100803,2	78328,46	61136,98	47924,77
sum	4043563	3558120	3155894	2819968	2537263	2297593	2092970
PI	1,617425	1,423248	1,262358	1,127987	1,014905	0,919037	0,837188

Table 11. Profitability index method (Case 2)

Discount rate	4	6	8	10	12	14	16
	368076,9	361132,1	354444,4	348000	341785,7	335789,5	330000
	353920,1	340690,6	328189,3	316363,6	305165,8	294552,2	284482,8
	340307,8	321406,3	303879	287603,3	272469,5	258379,1	245243,8
	327219	303213,5	281369,4	261457,6	243276,3	226648,3	211417
	314633,7	286050,4	260527,2	237688,7	217211	198814,3	182256,1
	302532,4	269858,9	241228,9	216080,6	193938,4	174398,5	157117,3
	290896,5	254583,9	223360,1	196436,9	173159,3	152981,2	135445,9
	279708,2	240173,5	206814,9	178579	154606,5	134194	116763,7
	268950,2	226578,7	191495,3	162344,6	138041,5	117714	100658,4
	258606	213753,5	177310,5	147586	123251,4	103257,9	86774,48
	248659,6	201654,3	164176,4	134169,1	110045,9	90577,13	74805,59
	239095,8	190239,9	152015,1	121971,9	98255,23	79453,62	64487,58
	229899,8	179471,6	140754,8	110883,5	87727,88	69696,16	55592,74
	221057,5	169312,8	130328,5	100803,2	78328,46	61136,98	47924,77
sum	4043563	3558120	3155894	2819968	2537263	2297593	2092970
PI	1,123212	0,988367	0,876637	0,783324	0,704795	0,63822	0,581381

7 Conclusion

In this paper it is shown that transition from 10 to 20 kV voltage level for investment costs (2 500 000,00 and 3 600 000,00 km) is cost-effective.

In Case 1 where investment costs are 2 500 000,00 km the time of return of invested costs is 7 years. Discount rates up to 12% are allowed. For these discount rates IRR is positive and PI is greater than 1.

For Case 2 investment costs are 3 600 000,00 km and the time of return of invested costs is 10 years. Discount rates up to 4% are allowed. For these discount rates IRR is positive and PI is greater than 1.

Comparing these two cases it can be concluded that Case 1 is more acceptable from the aspect of cost-effectiveness but it may require additional investments for the upcoming period of time unlike the Case 2 where elements of the system will last longer since they are replaced completely. For the end, investment costs of 3 600 000,00 km are likely to be the only costs for the next 30–40 years.

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