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COST-BENEFIT ANALYSIS OF THE DISTRIBUTION NETWORK TRANSITION TO 20 KV OPERATING VOLTAGE

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Abstract

The focus of the development of modern medium voltage distribution networks includes the transition from 10 kV to 20 kV operating voltage. This paper, based on the estimation of the preparation in distribution network, presents the costs of the transition to a higher voltage level. The costs are divided by investors and key items that has to be modified in network. In the second part of analysis is presented economy benefit after transition to 20 kV through to comparation of the technical losses costs in the network at 10 kV and 20 kV operating voltage. A the result of cost-benefit analysis, in the long term period, are the savings in costs if distribution network operates on 20 kV. The distribution network Citluk owned by JP EP HZHB d. d. Mostar was taken for analysis.

Keywords: distribution network; 20 kV; technical losses; cost-benefit analysis

1. Introduction

"Elektro-Citluk" is the part of distribution area "DP JUG" owned by JP EP HZHB d. d. Mostar. The distribution network of "Elektro Citluk " is one of the most perspective network for transition from 10 kV to 20 kV operating voltage, so it's important to do detailed analysis of distribution network with costs and benefits of transition to a higher voltage level for distribution area Citluk. Operating conditions in the distribution area of the Citluk municipality, the increase in electrical consumption, the load in the distribution network and the lifespan of the existing elements require continuous planning of the development and construction of the distribution network.

Therefore, the studies of short-term and medium-term development of the distribution network with dynamic plans are made, which in addition to providing answers to the questions of where and what needs to be built or replaced in the distribution area also provide answers to questions in which planning year it was optimal to carry out work. Assessment of the current state of electricity consumption and characteristic loads is an important participant in any planning of energy network development. According to previous tests, electricity losses are large due to various factors, such as the age of the equipment and unregistered consumption.

During the previous year, a lot of work was done on these shortcomings, but the losses in the network do not meet world standards. The replacement of 10 kV equipment in the distribution network with 20 kV operating voltage has been taking place in recent years as part of regular network maintenance and thus the dynamic of the transition to 20 kV which is long-term process, is taking place. In the meantime, we are currently working on the Study of the transition to 20 kV with current data on the equipment that remains to be replaced, technical solutions that need to be adjusted for proper operation of the network, etc. This article is done according to the current Study of transition to a higher voltage level. The first part of paper presents the cost of transition by key items and investors with the total costs of investment. The second part shows the cost savings by comparing the technical losses in network during operation at 10kV voltage and 20 kV voltage. Based on the calculation from the energy balance from 2019, and the approximate method of calculating losses in the MV network, an estimate of the loss savings is given when the network is switched to 20 kV operating mode. Accordingly, an analogous analysis was made for a ten-year period. As a result, there are cost savings in the transition of network to a higher voltage level as one of the benefits. In this paper, economical aspect of cost-benefit analysis is presented.

The process of transition from 10 kV to 20 kV takes place in several phases, and its basic characteristic is that it is economically optimal as a long-term process, with a total duration of several decades. According to the available literature [6] and the experiences of HEP [7], [8], the characteristic phases of the transition process from 10 kV to 20 kV:

- **first phase** - several decades: installation of components of the voltage level of 20 kV through regular maintenance of the network in operation at 10 kV,
- **second phase** - several years: accelerated replacement of the remaining components of the 10 kV voltage level for the transition to 20 kV and
- **third phase** - a few days: final transition of the network to 20 kV operation.

The implementation of the final transition to 20 kV operating voltage should be carried out in an organized manner, with great preparations and with mandatory strict application of protective measures, rules and safety measures when working on distribution power plants. Municipality Citluk is powerd by two large transformer substations TS 110/10(20)/10 kV Citluk and the new TS 110/20/10 kV Citluk 2. Cost analysis of transition from 10 kV to 20 kV is obtained by estimation of equipment condition and preparation of distribution network. The estimation of distribution network preparation is based on operating voltage level and equipment functionality such as:

- 10(20) kV equipment in TS 110/10(20)/10 kV Citluk,
- 10(20) kV overhead conductors and cables,
- equipment in TS 10(20)/0,4 kV.

TS 110/10(20)/10 kV Citluk has 14 medium voltage 10 kV terminals as follow:

- DV Vionica,
- KO Međugorje,
- KO Grad,
- KO Dom zdravlja,
- KO Sluzanj,
- DV Blatnica,
- KO Gradnici,
- KO Zitomislici,
- KO Vodozahvat,
- KO Vinarija,
- KO Tromeda,
- KO Bungalovi,
- KO Bijakovici,
- DV Zito.

TS 110/20/10 kV Citluk 2 was put in operation in September 2017. and was designed to ensure an increase in transmission capacity and backup supply to southern part of Citluk, part of Capljina (Studenci i Zvirovici) and northern part of Ljubuski, also minimize the overload of transformer substation Citluk. But this substation is not the subject of this paper.

2. Review of transition costs to higher voltage level

This chapter presents an overview of transition costs and expected benefits after transition to 20 kV operating voltage for distribution area supplied by transformer substation Citluk. Transition costs include the costs of preparation (such as project documentation and implementation of necessary measurements), costs of procurement and installation of equipment for neutral point (“NP”) grounding, container plant for intertransformation 20/10 kV, 10 kV cables replacement costs, costs of reconstruction of transformer stations and replacement of 12 kV equipment with new 24 kV equipment. Table 1 shows the costs of transition to 20 kV operating voltage including key items and ownership.

Name of costs	**TS 110/10(20)/10 kV Citluk**	
	Costs of EPHZHB (BAM)	**Costs of other investors (BAM)**
Preparation costs	100.000,00	
Neutral point grounding in TS Citluk	-	80.000/550.000[1]
Procurement of container plant for intermediate transformation of 20/10 kV	400.000,00	-
Replacment od distribution transformers in TS 10(20)/0,4 kV	467.402,00	227.168,00
Replacment of meduim voltage blocks	110.856,00	145.229,00
Replacement of 10 kV equipment in TS 10(20)/0,4 kV	193.019,00	10.008,00
Reconstruction of armored substations	215.042,00	69.729,90
Reconstruction of construction part in tower substations and grounding equipment in TS 10(20)/0,4 kV	383.900,00	15.000,00
Replacment of 10 kV equipment on 10 kV transmission lines	183.626,00	-
Replacment of underground 10 kV cables and installation of new 20 kV cables	98.400,00	-
TOTAL:	**2.152.246,00**	467.135,00 + 80.000/550.000 („Elektroprijenos BiH“)
Total *(including partial compensation in TS 110/10(20)/10 kV):* **2.699.381,00 BAM** Total *(including resonant grounding in TS 110/10(20)/10 kV):* **3.169.381,00 BAM**		

Table 1. Transition costs by key items and ownership

The estimation of costs is based on inspection of distribution substation 10(20)/0,4 kV and distribution medium voltage network (transmission lines and cables). Equipment prices are based on current market prices and the costs of electrical installation works are based on “Price List of Distribution network services” [1] and market prices of construction works. The cost of resonant grounding of neutral point are estimated on the experience of Croatian “HEP” [2] and Bosnian “EP BiH” [3] while the cost of partial compensation grounding is based on experience in applying this solution such as Croatian operator of distribution system “HEP ODS Elektroistra Pula. According to the analysis, it can be concluded that total cost of the distribution network transition to 20 kV operating voltage would be in amount of 2.699.381,00 – 3.169.381,00 BAM, depending on method for neutral point grounding in TS Citluk.

Also, according to the ownership of equipment and facilities, the cost can be divided into the costs of “JP EP HZHB d. d. Mostar”, the costs of “Elektroprijenos BiH a.d. Banja Luka” and the costs of other investors (III. part). Since “Elektroprijenos BiH a.d. Banja Luka” is the owner of the TS Citluk, all the equipment that will need to be installed (equipment for grounding of neutral point) is the property of this company. The estimated costs depending on method of NP grounding amount to 80.000,00-550.000,00 BAM. The costs of reconstruction of the substations owned by third parts, for entire network, amount to 467.135,00 BAM. Analysis does not include medium network terminals KO Ljubuski and KO Capljina, which are connected to TS 110/20/10 kV Citluk 2, because they are in regular maintenance of branches Ljubuski and Capljina.

The total estimated cost of transition to 20 kV of entire distribution network Citluk, which include the entire distribution network owned by “JP EP HZHB d. d. Mostar” are 1.652.245,00 BAM. The transition costs of medium voltage network to the 20 kV, according to the terminal from TS Citluk (excluding NP grounding equipment, intertransformation 20/10kV and preparation costs) are shown in Table 2.

[1] If manually adjustuble compensation inductor in conjuction with a low-ohm resistor per 110/10(20) kV transformer is selected for grounding neutral point in TS Citluk, the price would be approximately 80.000,00 BAM (40.000,00 BAM per transformer). In the case of grounding by automatic compensation choke without changing the existing protection, the total investment cost would be approximately 550.000,00 BAM (2 pieces of choke).

No.	TS 110/10(20)/10 kV Citluk	The price (BAM)		Total (BAM)
		“JP EP HZHB”	“III. Parts”	
1.	DV Vionica	46.439,00	0,00	46.439,00
2.	KO Medugorje	33.318,00	28.914,00	62.232,00
3.	KO Grad	0,00	161.021,00	161.020,00
4.	KO Dom zdravlja	17.055,00	78.813,00	95.867,00
5.	KO Sluzanj	204.102,00	36.916,00	241.018,00
6.	DV Blatnica	459.228,00	39.927,00	499.155,00
7.	KO Gradnici	317.496,00	1.330,00	318.826,00
8.	KO Zitomislici	22.543,00	69.730,00	92.273,00
9.	KO Vodozahvat	70.577,00	0,00	70.577,00
10.	KO Vinarija	216.862,00	0,00	216.862,00
11.	KO Tromeda	89.703,00	26.620,00	116.323,00
12.	KO Bungalovi	83.639,00	23.865,00	107.504,00
13.	KO Bijakovici	4.251,00	0,00	4.251,00
14.	DV Zito	87.032,00	0,00	87.032,00
Total (BAM)		**1.652.245,00**	**467.136,00**	**2.119.381,00**

Table 2. The transition costs to 20 kV operating voltage by medium voltage terminals

3. The costs of electrical energy losses

The grid losses are defined as the difference between energy delivered to the grid and the energy taken from the grid. Electricity losses are divided into technical losses and commercial losses. Technical losses are a result of the distribution of electricity through the network elements to the metering point of the customer.

Commercial losses are the result of unregistered consumption, non-simultaneous reading of electricity meters and subjective errors. Technical losses of electrical energy for distribution area Citluk were obtained on an approximate method of calculating losses in the medium voltage network. The usable time of the peak load T_v is calculated as the ratio of the total annual energy that is taken up from the grid Wuk and the realized peak load P_m:

$$T_v = \frac{W_{uk}}{P_m}\ [h] \tag{1}$$

The peak load factor F_v:

$$F_v = \frac{T_v\ [h]}{24 \times 365\ [h]} \tag{2}$$

The annual duration of active power peak losses in distribution network T_g, with factor of losses 0.17, is caluclated according to:

$$T_g = \left[0.17 \times \frac{T_v}{24 \cdot 365} + 0.83 \times \left(\frac{T_v}{24 \times 365}\right)^2\right] \times 24 \times 365\ [h] \tag{3}$$

The costs of electrical energy losses C_{gE} refer to the cost of additional energy (fuel, water…) to produce each kWh lost in the network. As follow:

$$W_{gE} = T_g \times P_{g,Cu} + T_n \times P_{g,Fe} \tag{4}$$

$$C_{gE} = W_{gE} \times k_E \tag{5}$$

where are:
W_{gE} - total annual losses of electrical energy [MWh],
T_g - annual duration of active power peak losses [h],
T_n- nominal time 8760 [h/god],
$P_{g,Cu}$ - power losses in the medium voltage network due to load [kW],
$P_{g,Fe}$ - idle power losses in the medium voltage network [kW],
C_{gE} - the costs of electrical energy losses [BAM],
k_E - the price of electrical energy losses [BAM/kWh].

3.1. The costs of electrical energy losses in the year 2019

Annual losses of electrical energy in the distribution network Citluk in the period from 2015 to 2019 have been 12% of the electrical energy taken from the grid. According to calculations for 2019, total technical losses of the active power for 10 kV network, at the time of peak load, were 1102,8 kW. Losses in iron (constant losses) of 10 kV network are 110,5 kW, and losses in copper (variable load-dependent losses) of 10 kV network are 902,3 kW.

The price of energy losses is determined on the valid prices of public service provider according to the decisions of Regulatory Commission for Energy in Federation of BiH (FERK). If we assume that the price of electrical energy losses is $k_E = 0{,}09 \left[\frac{BAM}{kWh}\right]$, and for the average value of the equivalent duration of the peak power (for 2019) is taken Tv, than the annual costs of electrical energy losses C_{gE}, in 10 kV network are:

$$C_{gE} = W_{gE} \times k_E \tag{6}$$

$$C_{gE} = 3.148.300\ [kWh] \times 0{,}09\ \left[\frac{BAM}{kWh}\right] \tag{7}$$

$$C_{gE} = 283.347{,}00\ [BAM] \tag{8}$$

Using the Power Factory software tool, it is possible to switch distribution network to operate in 20 kV and using the same peak load date for 2019, the costs of electrical energy losses are:

$$C_{gE} = W_{gE} \times k_E \tag{9}$$

$$C_{gE} = 1.731.523\ [kWh] \times 0{,}09\ \left[\frac{BAM}{kWh}\right] \tag{10}$$

$$C_{gE} = 155.837{,}00\ [BAM] \tag{11}$$

So, the conclusion is that by switching the existing 10 kV network to 20 kV operating voltage, the savings would amount to 127.510,00 BAM and the losses would be lower for 1.82 times. Since electrical energy consumption depends on many different factors, there were analogous analysis made for the period 2019 – 2028 (10-year period), assuming annual growth/decline rates for consumption scenarios +/- 0,3 %, +/- 0,5 % and +/- 0,8 %. The results are shown in Table 3.

Avarage consumption growth rate [%]	The savings [kWh]	The savings [BAM]
+ 0.3	14.522.639	1.307.038
- 0.3	13.845.413	1.246.087
+ 0.5	14.758.104	1.328.229
- 0.5	13.629.022	1.226.612
+0.8	15.120.815	1.360.873
- 0.8	13.312.831	1.198.155

Table 3. The estimation of savings in the case of 20 kV operating voltage (2019 - 2028)

According to presented results, the estimated savings in the ten-year period, depending on the trend of consumption growth rate and including the average purchase price to cover losses of 0,09 BAM/kWh, ranges from 1.19 to 1.36 million BAM. The cost of purchasing electricity to cover losses may fluctuate, so the expected financial savings may be more significant than reported in the previous analysis.

4. Conclusion

This paper presents an estimate of the costs of distribution network transition from 10 kV to 20 kV operating voltage in Citluk, as well as the savings by compering technical losses in the distribution network at 10 kV and 20 kV operating voltage. The costs estimation was performed according to current estimation of the preparation in distribution network Citluk.

According to analysis, the total costs of distribution network transition to 20 kV operating voltage is about 2,7 - 3,1 million BAM, depending on treatment of neutral point in TS 110/10(20)/10 kV Citluk. The total estimated costs of transition to 20 kV which include the whole distribution network owned by „JP EP HZHB d.d. Mostar“ is about 1,65 million BAM. Design and analysis of medium voltage network is done in the software tool DigSilent PowerFactory, and based on input parameters and approximate calculation method, the results of technical losses and costs for previous year were obtained, as well as estimates of savings for ten-year period. Based on data for the year 2019, the savings would be about 127.510,00 BAM, relatively the losses would be lower 1.82 times by switching the existing 10 kV network to 20 kV operating voltage. The estimation of savings for ten-year period is about 1.19 - 1.36 million BAM depending on price od electrical energy, which may vary. As result of cost-benefit analysis is the savings in costs of electrical energy losses in the long term period. In this paper are presented an economic overview of the investment and savings on losses, but it is a complex process that takes years and therefore there is a dynamic plan for the transition of the network to 20 kV.

According to research in this paper the next steps will be the following:

- based on the dynamics analysis, it can be concluded that the distribution network Citluk is already in the first phase and partly in the second phase of the transition to 20 kV voltage new because equipment of nominal insulation 24 kV has been installed for decades. (MV blocks, line disconnectors, insulators).
- finishing the Study of transition to 20 kV operating voltage
- development of an investment plan and inclusion in the long-term business plans of the Company
- develop the dynamics of the implementation of activities
- implementation of the necessary measurements of capacitive earth fault currents and actual values of contact voltages and steps at TS 10(20)/0,4 kV
- creating project documentation
- coordination and planning with „Elektroprenos BiH“ regarding grounding of 20/10 kV distribution network and intertransformation points in TS 110/10(20)/10 kV Citluk, etc.

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