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POWER FLOWS AND SHORT CIRCUIT CALCULATIONS FOR 10 KV AND 20 KV OPERATING VOLTAGE OF THE DISTRIBUTION NETWORK

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Abstract

This paper analyses the current and voltage conditions of the distribution network „Čitluk", which proved to be a perspective for transition to the 20 kV voltage level, taking into account all given criteria: preparedness, needs and trends, cost-effectiveness, external influences and secondary indicators.
The analyses were performed using the software tool DIgSILENT Power Factory and the results were presented for the case of the highest power consumption in the network. The paper provides analyses and results of power flows for 10 kV and 20 kV operating voltage, analyses and results of three-phase short circuit for 10 kV and 20 kV operating voltage, anayses and results of two-phase short circuit for 20 kV operating voltage and the calculation of capacitive currents.

Keywords: power flows, short circuit, distribution network, operating voltage, analysis

1. Introduction

The transition from 10 kV operating voltage to 20 kV operating voltage is one of the strategic guidelines for the development of modern medium voltage distribution networks which, in addition to the 10 kV operating voltage distribution network, has a significant impact on the HV / MV transformation. The need for the transition of the distribution network from 10kV to 20 kV operating voltage is determined by the loads of MV lines, voltage conditions in the network and earth fault current in the MV network, as well as the current state of the network (ie preparedness of the network for switching to 20 kV operating voltage). According to the theory, the advantages of the transition from the 10 kV voltage level to 20 kV voltage level are:

- reduction of relative voltage drop: 4 times smaller relative voltage drop along 20 kV lines compared to the same 10 kV lines,
- reduction of current load of lines: 2 times lower current loads of 20 kV MV lines in relation to the same 10 kV lines,
- reduction of electrical energy losses in conductors: 4 times lower electrical energy losses in 20 kV lines compared to the same 10 kV lines.

Due to these advantages, the transition to 20 kV operating voltage is unquestionable as a basic guideline for the development of distribution networks.

In this paper, the current-voltage conditions of the distribution network at 10 kV and 20 kV operating voltage have been analysed.

Analyses were performed using the software tool DIgSILENT Power Factory. The paper deals with the analyses of power flows for 10 kV and 20 kV operating voltage, the analyses of three-phase short circuit for 10 kV and 20 kV operating voltage, the analyses of two-phase short circuit for 20 kV operating voltage and the calculation of capacitive currents.

Figure 1 shows a model of the considered distribution network “Čitluk”, which was made in the DIgSILENT Power Factory software tool.

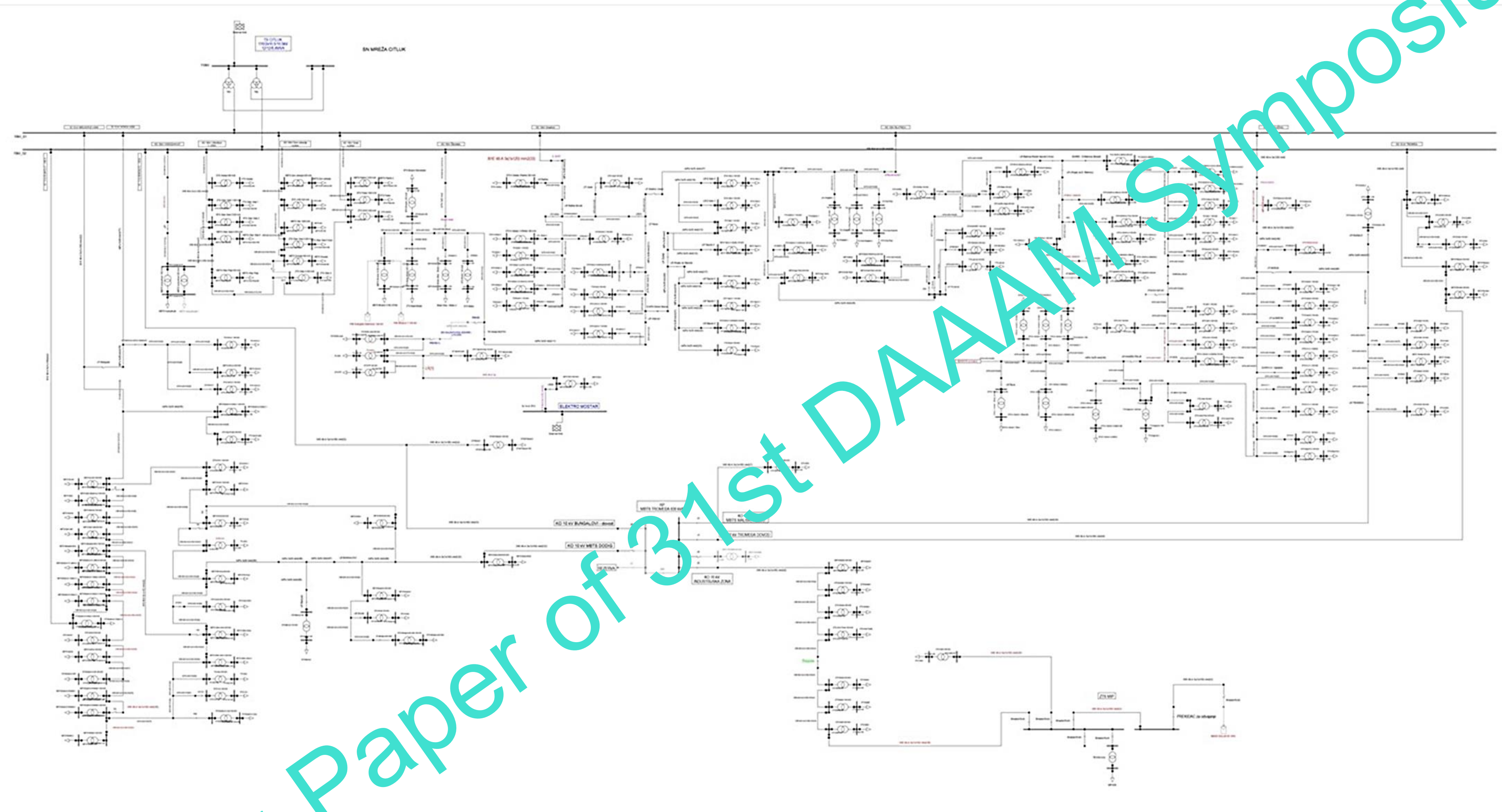
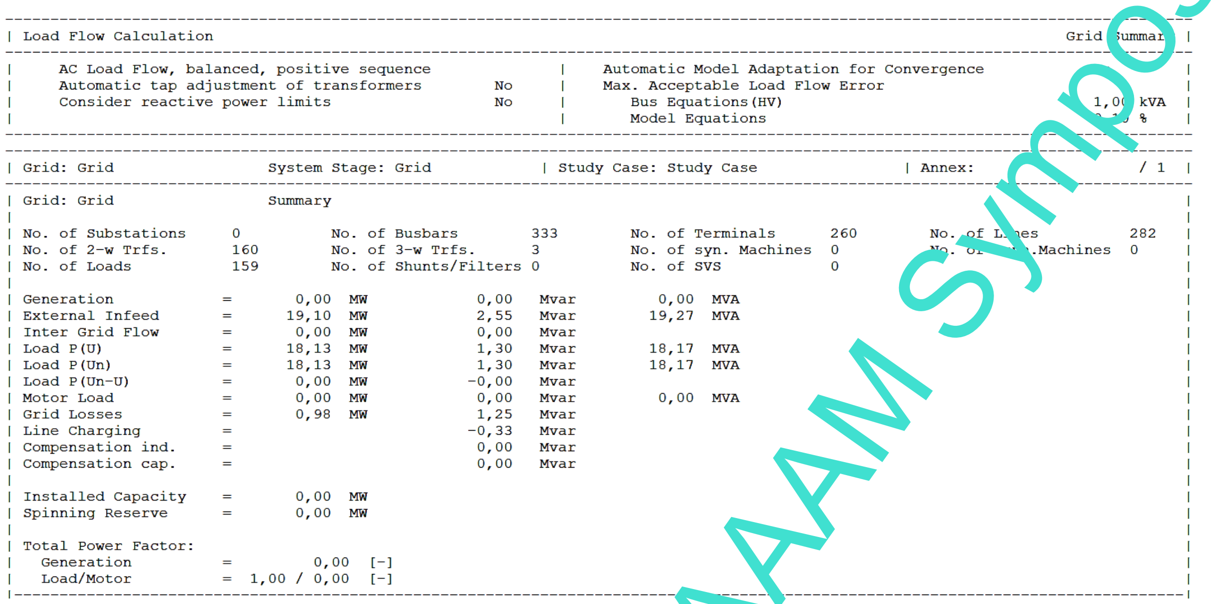


Fig. 1. Distribution network model

2. Power flow analyses

Figure 2 shows the power flow analysis results of current state of the network with summary network indicators.



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| Load Flow Calculation                                                                Grid Summary |
| AC Load Flow, balanced, positive sequence             | Automatic Model Adaptation for Convergence |
| Automatic tap adjustment of transformers     No       | Max. Acceptable Load Flow Error            |
| Consider reactive power limits               No       |   Bus Equations(HV)              1,00 kVA  |
|                                                       |   Model Equations                     %    |
| Grid: Grid          System Stage: Grid     | Study Case: Study Case         | Annex:         / 1 |
| Grid: Grid          Summary
|
| No. of Substations    0     No. of Busbars         333    No. of Terminals      260    No. of Lines           282
| No. of 2-w Trfs.      160   No. of 3-w Trfs.       3      No. of syn. Machines  0      No. of asyn.Machines   0
| No. of Loads          159   No. of Shunts/Filters  0      No. of SVS            0
|
| Generation          =     0,00  MW      0,00  Mvar     0,00  MVA
| External Infeed     =    19,10  MW      2,55  Mvar    19,27  MVA
| Inter Grid Flow     =     0,00  MW      0,00  Mvar
| Load P(U)           =    18,13  MW      1,30  Mvar    18,17  MVA
| Load P(Un)          =    18,13  MW      1,30  Mvar    18,17  MVA
| Load P(Un-U)        =     0,00  MW     -0,00  Mvar
| Motor Load          =     0,00  MW      0,00  Mvar     0,00  MVA
| Grid Losses         =     0,98  MW      1,25  Mvar
| Line Charging       =                  -0,33  Mvar
| Compensation ind.   =                   0,00  Mvar
| Compensation cap.   =                   0,00  Mvar
|
| Installed Capacity  =     0,00  MW
| Spinning Reserve    =     0,00  MW
|
| Total Power Factor:
|   Generation        =        0,00  [-]
|   Load/Motor        = 1,00 / 0,00  [-]
```

Fig. 2. Power flow analysis summary results for the current state of the distribution network

The scenario of the highest load in the distribution network (when the highest electrical energy consumption in the network is) was selected for analysis. For the year 2019, the highest load of the distribution network Čitluk was on December 31, at 7 p.m.

The results are as follows:

- total apparent power in the MV network is 19.27 MVA, total active power in the MV network is 19.10 MW, total reactive power in the MV network is 2.55 MVAr,
- total apparent power consumption in MV network is 18.17 MVA, total active power consumption in MV network is 18.13 MW, total reactive power consumption in MV network is 1.30 MVAr,
- total apparent power losses in the MV network are 1.38 MVA, total active power losses in the MV network are 0.98 MW, total reactive power losses in the MV network are 1.59 MVAr.

The following tables show the results of the analyses of power flows with voltage drops in the network. Due to the large number of data, voltage conditions data at the initial and final substations of individual lines were extracted from the obtained results. Separate results on MV buses (Table 1 and Table 3) and results on LV buses (Table 2 and Table 4) were also considered.

Name	Operating voltage	Voltage drop	Voltage drop [%]
	kV	kV	p.u.
BTS Frotea MV	10	9,960151	0,996015
MBTS Citluk Grad MV	10	9,932832	0,993283
MBTS Citluk Polje MV	10	9,932533	0,993253
MBTS Dodig Krstine MV	10	9,444047	0,944405
MBTS Dom zdravlja MV	10	9,963675	0,996368
MBTS Markovac MV	10	9,970569	0,997057
MBTS Matali (Bijakovici) MV	10	9,365213	0,936521
MBTS Padine 2 MV	10	9,958816	0,995882
MBTS Podbrdo 3 MV	10	9,065814	0,906581
MBTS Procištac MV	10	9,912704	0,99127
OTS Bijakovici-Ostojici 3 MV	10	9,535697	0,95357
OTS Vinarija MV	10	9,950153	0,995015
STS D. Hamzici 1 (Seve) MV	10	9,422655	0,942265
STS D. Hamzici 3 (Radišici) MV	10	9,427788	0,942788
STS D.Selo 2 MV	10	9,711014	0,971101
STS K.Gradac (Padine) MV	10	9,880588	0,988059
STS Padalovina MV	10	9,933433	0,993343
STS Služanj 4 MV	10	9,859907	0,985991
ZTS Majcino selo MV	10	9,605642	0,960564
ZTS Madišic MV	10	9,878965	0,987897
ZTS Satelit MV	10	9,861259	0,986126
ZTS Sivrici 1 MV	10	9,549884	0,954988

Table 1. Voltage drop analysis for 10 kV operating voltage (MV buses)

Name	Operating voltage	Voltage drop	Voltage drop [%]
	kV	kV	p.u.
BTS Frotea LV	0,4	0,400378	1,000945
MBTS Citluk Grad 4 LV	0,4	0,394722	0,986804
MBTS Citluk Polje LV	0,4	0,398079	0,995199
MBTS Dodig Krstine LV	0,4	0,376925	0,942312
MBTS Dom zdravlja LV	0,4	0,394398	0,985995
MBTS Markovac LV	0,4	0,397488	0,993721
MBTS Matali (Bijakovici) LV	0,4	0,370112	0,92528
MBTS Padine 2 LV	0,4	0,397443	0,993608
MBTS Podbrdo 3 LV	0,4	0,359839	0,899597
MBTS Procištac LV	0,4	0,395368	0,988421
OTS Bijakovici-Ostojici 3 LV	0,4	0,381398	0,953494
OTS Vinarija LV	0,4	0,392821	0,982052
STS D. Hamzici 1 (Ševe) LV	0,4	0,374202	0,935505
STS D. Hamzici 3 (Radišici) LV	0,4	0,37704	0,9426
STS D.Selo 2 LV	0,4	0,384195	0,960487
STS K.Gradac (Padine) LV	0,4	0,392356	0,98089

Name	Operating voltage	Voltage drop	Voltage drop [%]
	kV	kV	p.u.
STS Padalovina LV	0,4	0,392548	0,981371
STS Služanj 4 LV	0,4	0,389519	0,973797
ZTS Majcino selo LV	0,4	0,378505	0,946263
ZTS Mališic LV	0,4	0,393965	0,984913
ZTS Satelit LV	0,4	0,395988	0,989971
ZTS Sivrici 1 LV	0,4	0,380954	0,952385

Table 2. Voltage drop analysis for 10 kV operating voltage (LV buses)

Name	Operating voltage	Voltage drop	Voltage drop [%]
	kV	kV	p.u.
BTS Frotea MV	20	19,96496	0,998248
MBTS Citluk Grad MV	20	19,9661	0,998305
MBTS Citluk Polje MV	20	19,96601	0,9983
MBTS Dodig Krstine MV	20	19,72953	0,986476
MBTS Dom zdravlja MV	20	19,96662	0,998331
MBTS Markovac MV	20	19,98469	0,999235
MBTS Matali (Bijakovici) MV	20	19,70607	0,985303
MBTS Padine 2 MV	20	19,96432	0,998216
MBTS Podbrdo 3 MV	20	19,55741	0,977871
MBTS Procištac MV	20	19,95718	0,997859
OTS Bijakovici-Ostojici 3 MV	20	19,78556	0,989278
OTS Vinarija MV	20	19,97454	0,998727
STS D. Hamzici 1 (Ševe) MV	20	19,71186	0,985593
STS D. Hamzici 3 (Radišici) MV	20	19,71436	0,985718
STS D.Selo 2 MV	20	19,85342	0,992671
STS K.Gradac (Padine) MV	20	19,92834	0,996417
STS Padalovina MV	20	19,95217	0,997608
STS Služanj 4 MV	20	19,9318	0,99659
ZTS Majcino selo MV	20	19,80298	0,990149
ZTS Mališic MV	20	19,94116	0,997058
ZTS Satelit MV	20	19,93372	0,996686
ZTS Sivrici 1 MV	20	19,77769	0,988885

Table 3. Voltage drop analysis for 20 kV operating voltage (MV buses)

Name	Operating voltage	Voltage drop	Voltage drop [%]
	kV	kV	p.u.
BTS Frotea NN	0,4	0,401267	1,003167
MBTS Citluk Grad 4 NN	0,4	0,396745	0,991862
MBTS Citluk Polje NN	0,4	0,400094	1,000235
MBTS Dodig Krstine NN	0,4	0,393788	0,98447
MBTS Dom zdravlja NN	0,4	0,395193	0,987983
MBTS Markovac NN	0,4	0,398362	0,995905
MBTS Matali (Bijakovici) NN	0,4	0,389887	0,974718
MBTS Padine 2 NN	0,4	0,398379	0,995948
MBTS Podbrdo 3 NN	0,4	0,388562	0,971405
MBTS Procištac NN	0,4	0,39801	0,995024
OTS Bijakovici-Ostojici 3 NN	0,4	0,395681	0,989202
OTS Vinarija NN	0,4	0,394327	0,985818
STS D. Hamzici 1 (Ševe) NN	0,4	0,39165	0,979125
STS D. Hamzici 3 (Radišici) NN	0,4	0,394209	0,985522
STS D.Selo 2 NN	0,4	0,392917	0,982292
STS K.Gradac (Padine) NN	0,4	0,395722	0,989306
STS Padalovina NN	0,4	0,394277	0,985692
STS Služanj 4 NN	0,4	0,393812	0,984529
ZTS Majcino selo NN	0,4	0,39051	0,976276
ZTS Mališic NN	0,4	0,397641	0,994102
ZTS Satelit NN	0,4	0,400193	1,000484
ZTS Sivrici 1 NN	0,4	0,394548	0,986371

Table 4. Voltage drop analysis for 20 kV operating voltage (LV buses)

The improvement of voltage conditions is visible, see the reduction of voltage drop on individual terminals during the transition to a higher voltage level (20 kV). Voltage deviation of more than 10%, in accordance with the document “Network rules of the distribution system operator of the public utility Elektroprivreda Hrvatske zajednice Herceg Bosne d.d. Mostar “, in relation to the rated voltage does not occur.

3. Short circuit analyses

IEC 60909 / VDE 0102 standard was used in the calculation of short circuit currents. The IEC 60909 / VDE 0102 standard uses an equivalent voltage source on the bus on which the fault occurred and simplifies the superposition method (Complete method). The aim of this method is to achieve a short circuit calculation close to the actual value without the need for a previous load calculation. This option offers a sub-selection for the selected method, where it is possible to select the standard according to the year in which it was issued. In the analysis, calculations were performed for three-phase short circuit, two-phase short circuit and earth fault according to the stated norm. This information is important for the selection of elements protection, sizing of switches and dimensioning the selectivity of protection.

3.1. Three-phase short circuit for 10kV and 20kV operating voltage

An analysis of three-phase short circuit currents on 10 kV and 20 kV busbars TR1 and TR2 was performed for the case when transformers operate separately. In that case, the highest values of three-phase short circuit currents on individual busbars were observed, in order to properly set short circuit protections according to the new values of short circuit currents.

Busbar	Ik3 – 10 kV	Ik3 – 20 kV
TR1	12,634 kA	6,85 kA
TR2	11,462 kA	6,26 kA

Table 5. Three-phase short circuit on MV busbars of transformers TR1 and TR2

3.2. Two-phase short circuit for 20kV operating voltage

An analysis of two-phase short circuit currents on 20 kV busbars of 10 (20) /0.4 kV distribution substations in the Čitluk network was performed. In that case, the lowest values of two-phase short circuit currents on individual 20 kV busbars were observed, for the purpose of proper installation of short circuit protections. Due to the amount of data, the calculation results were extracted from the most distant MV buses, where the lowest values of two-phase short circuit currents were recorded, for the purpose of setting the protection properly, according to the new values of short circuit currents.

Lowest two-phase current	
Busbar name	kA
BTS Frotea MV	4,[illegible]91[illegible]34
MBTS Citluk Grad MV	3,894726
MBTS Citluk Polje MV	3,572947
MBTS Dodig Krstine MV	2,846491
MBTS Dom zdravlja MV	4,933068
MBTS Markovac MV	4,622922
MBTS Matali (Bijakovici) MV	2,138108
MBTS Padine 2 MV	4,376739
MBTS Podbrdo 3 MV	1,651618
MBTS Procištac MV	3,963889
OTS Bijakovici-Ostojici 3 MV	2,885819
OTS Vinarija MV	4,375481
STS D. Hamzici 1 (Ševe) MV	0,859905
STS D. Hamzici 3 (Radišici) MV	0,831526
STS D.Selo 2 MV	1,096724
STS K.Gradac (Padine) MV	3,730218
STS Padalovina MV	3,749885
STS Služanj 4 MV	2,461642
ZTS Majcino selo MV	3,056535
ZTS Mališic MV	3,489804
ZTS Satelit MV	2,965314
ZTS Sivrici 1 MV	3,534093

Table 6. Two-phase short circuit on MV busbars – 20 kV

3.3. Single-phase short circuit for 10kV and 20kV operating voltage

Since the distribution network of 10 kV operating voltage is not grounded, a single-phase fault is an earth fault. If the layout of 10 (20) kV feeders between the transformer transformers T1 and T2 is taken into account, as shown in Figure 1, the cumulative contributions of the capacitive currents of the feeders connected to the observed busbars are:

- for feeders connected to T1: 74 A,
- for feeders connected to T2: 73 A.

Assuming an operating condition in which all feeders are connected to one of the transformers, the total contribution of capacitive currents of all feeders is 147 A.

For the calculation of capacitive currents at 20 kV operating voltage, the cumulative contributions of the capacitive currents of the feeders connected to the observed busbars are:

- for feeders connected to T1: 150 A,
- for feeders connected to T2: 147 A.

Assuming an operating condition in which all feeders are connected to one of the transformers, the total contribution of capacitive currents of all feeders is 297 A.

According to the obtained results, it is evident that the earth fault current increases approximately 2 times by switching to a voltage level of 20 kV. Therefore, it is necessary to perform grounding of the neutral point in the network.

The issue of grounding the 10 (20) kV network neutral point is complex because of strict regulations which prescribe permissible contact voltages (especially on terrains with high specific ground resistance). The neutral point of the transformer can be grounded in different ways:

1) isolated neutral point
2) low-resistance grounding
2) partial compensation
3) resonant grounding

The optimal choice of grounding depends primarily on the value of capacitive current, protective and functional earthing of substations, the presence of cables in the MV network, specific ground resistance and the type of transformer.

4. Conclusion

The transition of the network operation from 10 kV to 20 kV level is a strategic measure of the transition from a three-voltage 110/35/10 distribution system to a two-voltage 110/20 kV. Also, as part of the strategic measure, the transition to 20 kV cannot be viewed as a separate process in the medium voltage network, but should be viewed as part of network development planning.

Several facts justify such a transition from a purely technical point of view:

- elimination of one transformation level reduces the total transformation losses in the system,
- the reliability of the whole system increases, because there is no more contribution to the unreliability of one transformation,
- compared to the 10 kV network, the 20 kV network has two times higher transmission power and approximately four times less operating losses,
- switching to 20 kV operation voltage solves most of the problems related to excessive voltage drops in the MV network.

With this paper, the advantages of the transition of the network operating voltage from 10 kV to 20 kV were shown on the example of the transition of the distribution network "Čitluk" to the operating voltage of 20 kV. Based on the performed analyses, it can be concluded that the transition to 20 kV operating voltage reduces all voltage drops which are significantly below the allowable limit of +/- 10% Un, with a twofold increase in network capacity and reduction of losses in the MV network. By simulating the operation of the network after the transition to 20 kV operating voltage, it is evident that there is a need of grounding the neutral point of the MV network. There are many ways of grounding, which are used in practice and the decision on the method of neutral grounding depends on the situation in the network connected to the substation. When deciding on the method of neutral grounding it is necessary to thoroughly consider all the advantages and disadvantages of individual modes of neutral grounding, and then choose the best technical and economical solution.

5. References

[1] Baričević, T.; Dudjak V. & Skok, M. (2014). Perspektiva i tehno-ekonomski uvjeti prelaska distribucijske mreže na 20 kV pogonski napon, Energetski institut Hrvoje Požar, Zagreb

[2] Međugorac, M.; Marijanović, M.; Ćorluka, N. & Glavina, J. (2019). Studija prijelaza s 10 kV na 20 kV pogonski napon poslovnice Elektro Tomislavgrad, JP EP HZ HB d.d., Mostar