

OVERVOLTAGE ANALYSIS DURING EARTH FAULT FOR DIFFERENT TREATMENT OF NEUTRAL POINT IN DISTRIBUTION NETWORK

ANALIZA PRENAPONA PRI NASTANKU ZEMLJOSPOJA KOD RAZLIČITOG TRETMANA NEUTRALNE TAČKE U DISTRIBUTIVNIM MREŽAMA

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Abstract: The paper consists of three parts. In the introduction and the first part of this paper are given basic theoretical considerations on possible ways for treatment of the neutral point in distribution grids with special reference to the method of neutral grounding of distribution transformers through a low ohmic resistor and a compensation coil. The second part gives the use analysis of a low ohmic resistor and a compensation coil as the future choice of neutral point grounding on the particular distribution grid powered by a substation TS 35/10 kV. In the third part of the paper, the results were obtained using an adequate dynamic distribution model, using the EMTP-ATP software package. Also, in this part, calculations are made for neutral grounding through a low ohmic resistor, a compensation coil, as well as in the case of isolated grids, and a comparison of the obtained values of the overvoltage coefficients.

Keywords: neutral point, low ohmic resistor, compensation coil, grounding, ground fault current, overvoltage

Sažetak: Rad se sastoji iz tri dijela. U uvodnom i prvom dijelu rada su data osnovna teorijska razmatranja o mogućim načinima tretmana neutralne tačke u distributivnim mrežama sa posebnim osvrtom na način uzemljenja neutralne tačke distributivnog transformatora preko maloomskog otpornika i kompenzacijske prigušnice. U drugom dijelu rada je izvršena analiza upotrebe maloomskog otpornika i kompenzacijske prigušnice kao buduće opredjeljenje za uzemljenje neutralne tačke na konkretnom dijelu distributivne mreže napojene iz trafostanice TS 35/10 kV. U trećem dijelu rada su dati rezultati dobiveni korištenjem adekvatnog dinamičkog modela distributivnog sistema, korištenjem programskog paketa EMTP-ATP. Također, u ovom dijelu su izvršeni proračuni u slučaju uzemljenja neutralne tačke preko maloomskog otpornika, kompenzacijske prigušnice kao i u slučaju izolirane mreže, te je izvršena usporedba dobijenih vrijednosti koeficijenata prenapona.

Ključne riječi: neutralna tačka, maloomski otpornik, kompenzacijska prigušnica, uzemljenje, struja zemljospoja, prenapon

INTRODUCTION

The main task for electric power utilities, engaged in activities of generation, distribution and supply of electricity, trading, representation and mediation in domestic and foreign electricity markets is to ensure reliable operation of the distribution system and to meet quality of delivered electricity in accordance with regulations. With opening of the electricity market, Distribution System Operator (here in after referred to as DSO) is being imposed to a requirement for „higher quality“ electricity supply, which also implies higher delivery reliability, and shorter de-energization intervals. In recent years a rapid development of residential and commercial zones, tourist centres, etc., has been recorded with a further trend of increase; general social development should be accompanied by an

appropriate electricity infrastructure. The extension of the power distribution network results in construction of new power lines (mostly cables), which significantly increase the overall value of the capacitive current.

With the increase of single Line-to-Ground fault current the conditions for execution of 10(20)/0.4 kV grounding and the propagation resistance are aggravated within the permissible limit values defined in the relevant regulations, which is directly related to hazardous voltage. All the above mentioned, refer to the need for a special focus on the analysis of neutral point treatment, that is, neutral point grounding in the TS 110/x kV transformer stations (and TS 35/x kV until their final abandonment).

Capacitive ground fault current in an isolated 10 kV network should not exceed 20 A, and in any case must not exceed 40 A with shortening of the shutdown period. In case of capacitive currents higher than 40 A, neutral point grounding should be made. Capacitive ground fault current in a 20 kV isolated network should not exceed 15 A, and in any case must not exceed 30 A with shortening of

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loses its major advantage, i.e. the possibility of ground fault self-extinction. In order to reduce the capacitive ground fault current, which exceed the limited values, it is possible to connect an inductive reactance between the transformer neutral point and the ground. In this way, the inductive current compensates for the capacitive ground fault current. The inductive reactance is adjusted to obtain resonance between reactance and the capacity to ground per grid phase, so it is called a resonant grounding grid. The illustration of a Line-to-Ground fault in case of neutral point grounding by Petersen coil is shown in Figure 2.a). The corresponding vector diagram for the duration of ground fault is shown in Figure 2b).

The equivalent impedance viewed from the fault point is defined as [4]:

$$Z_0 = \frac{j3L_{PR} \frac{1}{j\omega C_0}}{j\left(3\omega L_{PR} - \frac{1}{\omega C_0}\right)} \quad (3)$$

It is desirable that current I_{PR} , which is approximately equal to the ground fault current in the grid I_z , flows through the reactance coil X_{PR} [4]:

$$I_{PR} = I_z - I_{L1} - I_{L2} \quad (4)$$

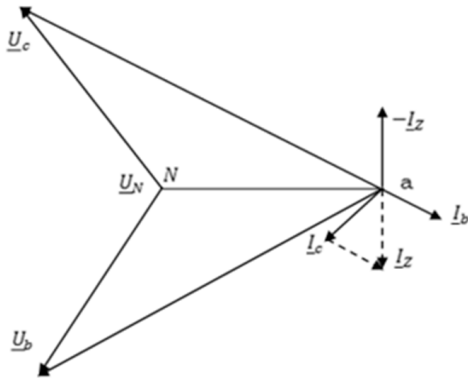
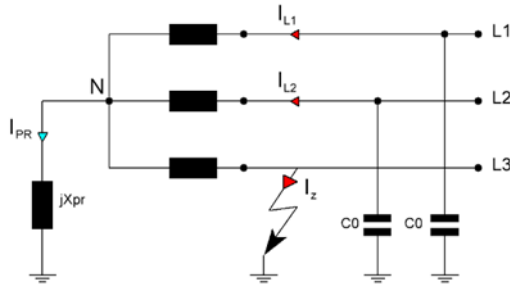


Figure 2: a) Illustration of a Line-to-Ground fault in case of neutral point grounding by Petersen coil, b) Vector diagram during the ground fault

The condition of resonant neutral point grounding formally comes down to $3\omega^2 L_{PR} C_0 = 1$, [4]. Mainly in practice, total compensation is avoided to prevent resonant surges that may occur in interruption of phase conductors. The neutral point coil is practically designed with feeders or splices, projected (usually) for nominal currents: 5; 10; 15; 20; 25; 30 A.

In case of a failure, leakage currents of healthy phases flow towards the transformer neutral point. This also applies for all other healthy transmission lines in the grid, i.e. the sum of conductivity currents in all transmission lines flows from the grid to the transformer neutral point. Through the faulty phase, in case of total compensation, only the active part of these currents flow and the active part of the coil current and together they represent the earth fault current. The capacitive part of the earth fault current is compensated by the coil inductive current. The transformer neutral point voltage, in case of ground fault, becomes the phase voltage of the grid, while the voltage of the healthy phases becomes the phase to phase voltage.

Herein in the case of single Line-to-Ground fault, the earth fault current flows from the phase with fault to the ground fault point and has a significantly lower value. This current is often called residual ground fault current and consists only of the active component in case of total compensation.

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In the case of incomplete compensation, two instances may occur. The first instance is when the capacitive component of the ground fault current is higher than the inductive component of the coil current $L_{PR} < \frac{1}{3\omega^2 C_0}$. The second instance is when $L_{PR} > \frac{1}{3\omega^2 C_0}$, i.e. the capacitive ground fault

current component is lower than the inductive component of the coil current. In the first case it is referred to as an „undercompensated“ grid, and in the second case it is an „overcompensated“ grid. In the second case the reactive component of current also exists in the residual ground fault current.

Conditions for single Line-to-Ground fault self – extinction, as one of the main advantages of these grids depend primarily on the value of the ground fault current. In this case, it refers to the residual ground fault current. Conditions for ground fault extinction, after the cause of failure passes also significantly depend on the speed of voltage establishment on the phase with fault, so called „reverse voltage“, which aims to re-establish the ground fault. In incompletely compensated grids reverse voltage has a pulsatile – oscillatory flow. For larger inaccuracies in compensation, reverse voltage may have an overvoltage up to 1.7. However, in this case also the amplitude of reverse voltage slowly rises and reducing the possibility of ground fault re-establishment.

Neutralizing the ground fault current is done by installing a coil that is connected between the neutral point of the respective transformer station and the ground. It adjusts the reactance X_{PR} so that it resonates with the capacitance to ground X_{C0} of lines, so that the resulting ground fault current that remains has small amplitudes. The active component of current, i.e. the residual current I_R is obtained due to losses on the coil. The residual current and the ground fault current are in phase and occur simultaneously. If a ground fault occurs in an overhead network (e.g. break through isolator) self-extinguishing can occur. When using neutral point grounding method through the compensation coil, the aim is to select the reactance of the coil $X_{PR} = \omega L_{PR}$ in such a way to compensate the reactance capacities to ground $X_{C0} = \frac{1}{\omega C_0}$ of overhead lines, resulting

from the total overhead line capacities to the ground. In this case, the reactive part of the zero-sequence impedance is equal to $X_{PR} - X_{C0}$. In the case of total compensation $X_{PR} = X_{C0}$, it can be said that the network is adjusted and the current is consequence of the operating losses in the coil, which is most often neglected. The reactance X_{C0} is adjustable accordant to each change of network configuration. Therefore, to maintain the residual current at the same value, the coil inductance value must also be changed. Based on the aforementioned in this section the inductance value of the compensation coil will be calculated in such a way that the current value of the single Line-to-Ground fault I_z is known.

The total value of the ground fault current in a 10 kV or 20 kV network can be written according to the equation, [7].

$$I_z = \sqrt{3} \omega C_0 U_L \quad (5)$$

For resonant grounded networks into account must be taken the order of operations during network manipulation. The compensation coil, in the moment of manipulation in the network, can have considerable magnetic energy, which must be discharged through small capacities of lines and other network elements, which can cause significant overvoltages. Particularly large overvoltages can occur when two-phase to ground faults are turned off, since the fault current in the faulty phase is shifted by 90° compared to the current through the coil, so, in the coil can remain considerable magnetic energy.

2. ANALYSIS OF A SINGLE LINE-TO-GROUND FAULT IN DISTRIBUTION GRID SUPPLIED FROM THE CONSIDERED TS 35/10 KV

In this section of the paper, a part of real distribution network for a particular TS 35/10 kV (Figure 3) is given and implemented in the software package EMTP - ATP. The EMTP - ATP software package is used for computer analysis of electromagnetic phenomena resulting from switching operations, the formation and elimination of short circuits. The results of the calculation of ground fault currents and voltage of line in failure (using EMTP-ATP) for the selected a part of real distribution network which is supplied from the considered TS 35/10 kV are shown in Figures 4, 5 and 6, respectively. Analysis of stationary and transient overvoltages have been carried out for the characteristic very long 10 kV sections. In the part of the analyzed distribution area in Bosnia and Herzegovina, electricity is supplied from the transformer station TS x/10 kV through 55 medium voltage lines, partly constructed with overhead transmission lines 68,487 km and partly by cable 38,547 km (mixed air-cable sections).

Computer modelling of elements and parts of the distribution system was performed in order to analyze transient phenomena in the selected distribution network. A single-line diagram of the test distribution system supplied from the 35/10 kV transformer station is given in Figure 3. The 10 (20) kV network neutral points were initially not grounded (isolated). Today, there is a tendency for such systems to be abandoned due to their disadvantages. In such systems the neutral point is separated from the ground and the only connection to the ground is achieved through the ground capacitances of overhead transmission lines and cables.

In the events of ground faults, currents flow through the ground capacitance of the healthy phases. Also, it can be concluded that fault currents depend on the capacitive current of the grid and the transient resistance.

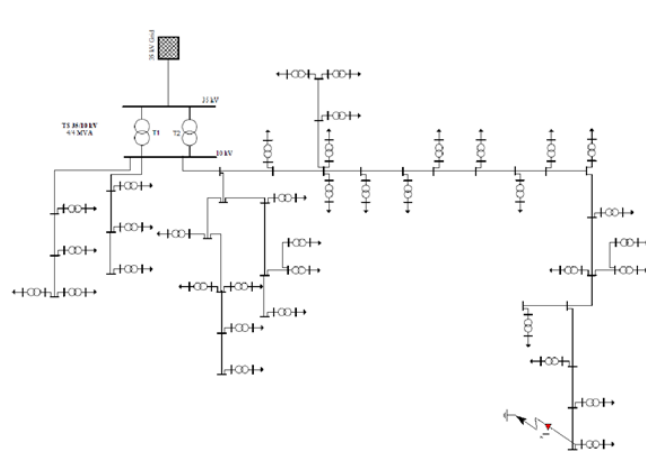


Figure 3: Single line diagram of the distribution network which is supplied from the considered transformer station TS 35/10 kV

The healthy phase overvoltage factor in the stationary part of the fault with some small transient resistance can be up to 1.9. In the transient fault, the overvoltage factor may have significantly higher values in case of intermittent ground fault, [2].

According to the calculation results, the value of capacitive ground fault currents on the observed distribution network is 136.54 A, as one of the basic indicators of the performed analysis. The distribution network of the transformer station under consideration is predominantly a rural network, with combined construction as an air-cable network.

The results in this paper represent values obtained on the model in which the worst case single Line-to-Ground fault circuit was analyzed from the aspect of surge factors that occur at the beginning and at the end of a line. The short circuit is simulated in the moment when the peak voltage is reached at the phase where the short circuit occurs. The short circuit occurs at the end of the longest power transmission 10 kV line in the observed distribution network, Figure 3.

Since the rated voltage of the observed distribution network, supplied from the considered transformer station is 10 kV, by expression (1) can be calculate the value of the low ohmic resistor by grounding the distribution network through the low ohmic resistor and limiting the ground fault current to 300 A.

Since the total value of the ground fault current in the given distribution network is $I_z = 136.54$ A, using the expression (5) calculation of the total value of capacitance to ground of lines in the observed network can be done, which is:

$$C_0 = \frac{I_z}{3\omega^2 U_L} = 25.1 \mu F$$

Considering the condition of ground fault current compensation, it is possible to calculate the inductance of the compensating coil for total compensation according to the equation:

$$L_{PR} = \frac{1}{3\omega^2 C_0} = 0.135 H$$

For a mixed overhead transmission lines-cable distribution network in the case of ground fault (which is the most common fault) for relatively small capacitance current values of less than 20 A, it can be assumed that the arc will shut down itself if a temporarily fault occurs. In this case, there is no shutdown of lines, which leads to the better power quality supply to customers. There is no problem with the performance of grounding conductors if the ground fault currents are relatively small. The problems are existence of higher internal overvoltages and the appearance of high overvoltage factors due to intermittent overvoltages.

Analyzing the obtained results of the simulation for real distribution networks, it can be concluded that in stationary regime, for combined air-cable considered network (isolated neutral point) obtained capacity current of ground fault is 136.54 A, exceeding the 6.8 times of the limit values of self-extinguishment, Figure 4. This is intolerably and therefore action must be taken in terms of the neutral point grounding (switch to directly grounded neutral point) or separating the networks.

The Figure 6 is shown diagram of ground fault current in case when the network is grounded through low ohmic resistor. As said earlier the main point of practice of treating neutral points grounded with low ohmic resistor is reduction of internal surges and enabling more reliable protection work. To make internal surges in acceptable values, with resistor choices it should be achieved mostly the working character of fault current in place of single Line-to-Ground fault current. That is possible if certain conditions are met which were discussed in Chapter 1 of this paper. For the selected 10 kV distribution network it is provided with low ohmic resistor grounding with typed values of resistance and in this case would be achieved current limitation on the value 300 A. From the obtained results of the simulation (Figure 6), it can be concluded that the selected resistance value is correct, and the ground fault current is limited on the value of 300 A. In order to make a final decision on the neutral point ground treatment, it is necessary to make a techno-economic analysis. Determine whether there are areas with high value of specific ground resistance and with a reasonable investments for improving grounding of TS 10/0.4 kV. Also, it is not possible obtain sufficiently small grounding values, and in the case of a low resistance grounding is not applicable with the appropriate switch-off time of the protective devices. In this case, it is necessary to leave the neutral point isolated or to compensate the capacitive current.

The Figure 8 is shown a diagram of the ground fault current when the neutral point of the considered network is grounded over a resonant coil. Analyzing the obtained results of the simulation of a real distribution network, it can be concluded that for a given distribution network, in case of grounded neutral point is over a compensation coil, the ground fault current is 2.02 A.

In areas with large capacitive currents can be detected a relatively high number of ground faults, so it is recommended to use an automatic compensation coil. It is the most advanced technology solution, but requires significantly more investments. Therefore, the advantage of using a compensation coil is the following:

- The danger of too high potentials at the transformer stations grounding is minimized, and therefore there is no need for expenses for eventually grounding repair.
- Due to the low fault current, extinguish of the fault is enabled, so that each fault does not cause a line shutdown (comparison with low resistance grounding, which contributes to the improvement of the power quality supply.

- Due to arc extinguishment the return voltage increases more slowly than in isolated distribution networks and grounded through low resistance, for the same reason a small number of single Line-to-Ground fault develops into multi-phase faults, and from this aspect the number of faults is smaller for a resonant grounding than with an isolated neutral point (at equal conditions).

The disadvantages of the networks with a coil are the low sensitivity to high ohmic faults (possibly need for more sophisticated protection) and the compensation coil with the equipment represents a considerable investment cost. Using EMTP-ATP, calculations of the surge factor were performed, and the diagrams of voltages of the fault conductors are given in Figures 5, 7 and 9.

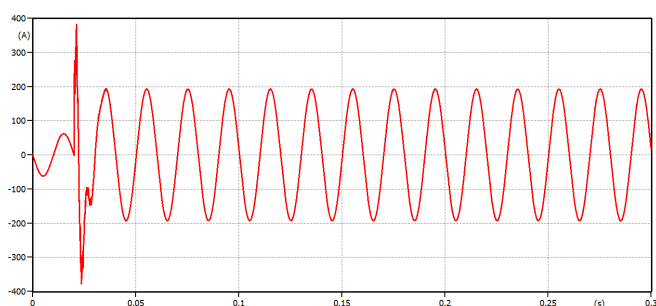
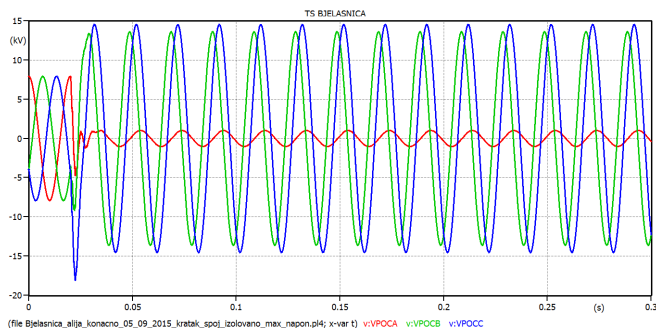
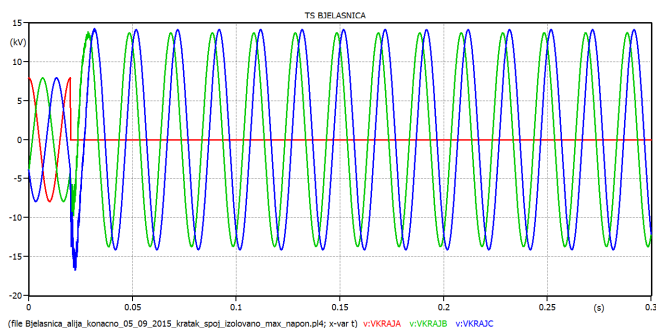


Figure 4: Ground fault current – isolated grid



a)



b)

Figure 5: Voltage of line in failure, short-circuit moment in $t=0.020$ s – isolated network, a) start of line, b) end of line

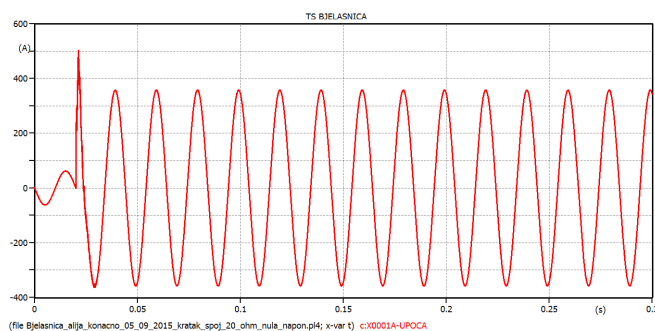
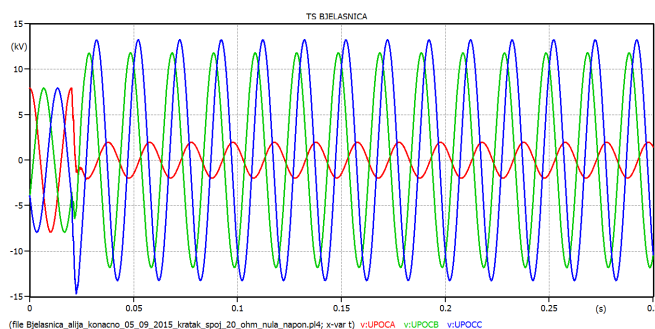
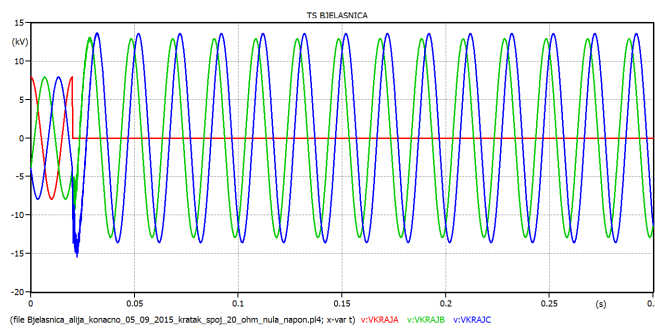


Figure 6: Ground fault current – grid grounded by low ohmic resistor ($R_N = 20 \Omega$)



a)



b)

Figure 7: Voltage of line in failure, short-circuit moment in $t=0.020$ s – isolated grid, a) start of line, b) end of line

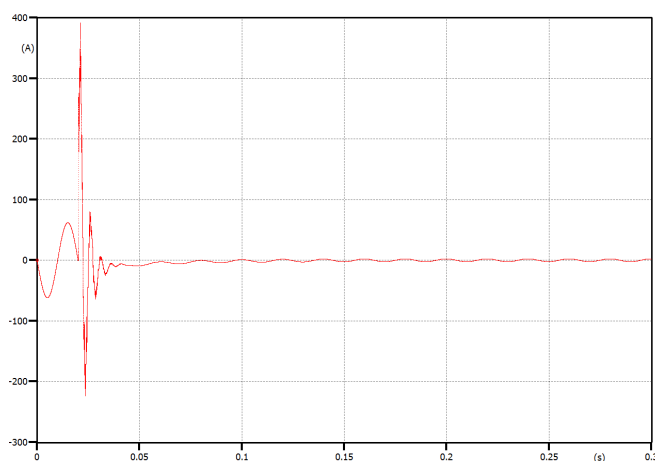


Figure 8: Ground fault current – grid grounded by Petersen coil ($L_N=0.135$ H)

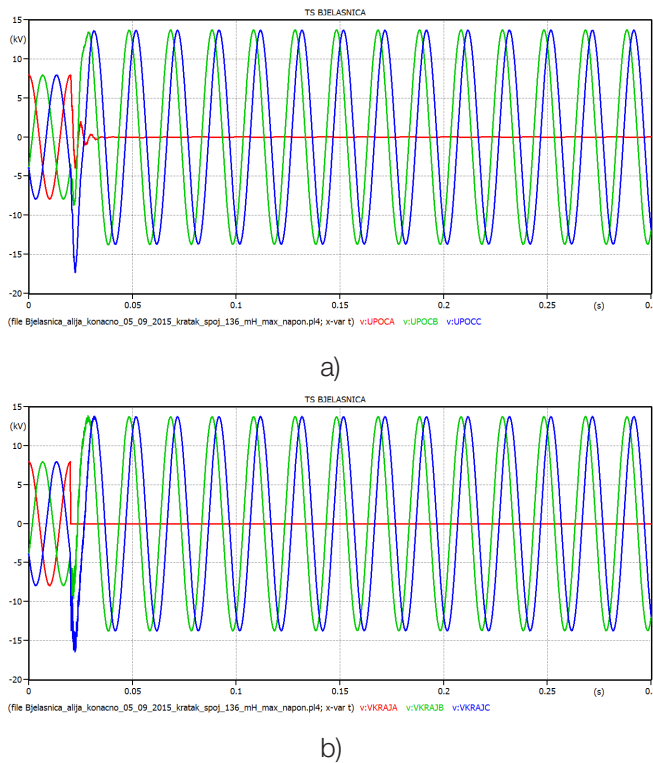


Figure 9: Voltage of line in failure, short – circuit moment in $t=0.020$ s – isolated grid, a) start of line, b) end of line

Comparative values of surge factor for the selected distribution network model in cases with the isolated neutral point, grounded over a low resistance or grounded over a compensation coil are given in Table I.

Table I: Overview of the Surge Factor Calculation Results, [6].

Neutral point treatment – Surge factors in stationary regime			
Measurement place	Isolated network (p.u.)	Low resistance grounding (p.u.)	Compensation coil (p.u.)
Start of line	1.726	1.619	1.677
End of line	1.697	1.662	1.678
Current I_z (A)	136.54	257.94	2.02
Neutral point treatment – Surge factors in transient regime			
Measurement place	Isolated network	Low resistance grounding	Compensation coil
Start of line	2.21	1.78	2.12
End of line	2.05	1.89	2.00

Analyzing the values of the surge factors given in Table I, it can be concluded that the highest values of the overvoltages are obtained at ground fault for case of an isolated network, $k=2.21$ p.u., and the lowest values of the overvoltages are obtained for the case when the neutral point is grounded over a low resistance, $k=1.78$ p.u. Because of very long line segments these differences are not too expressed.

3. CONCLUSION

The issue of transformers neutral point treatment in MV networks in Bosnia and Herzegovina has not been given adequate attention for many years. Former approaches to this issue must be changed. Under current conditions, most distribution networks in Bosnia and Herzegovina are isolated (over 90%), and ground fault currents have significantly exceeded the recommended values due to cable network expansion. The directional ground fault protection is often used to prevent operation underground fault with impermissibly high currents. Considering the values of ground fault currents, it is urgent to consider a proper way of neutral point grounding in the MV network.

The main goal of transition from a system with isolated neutral point to a system with low ohmic grounding is the reduction of internal overvoltage and enabling a more reliable protection. This also eliminates the intermittent overvoltages possibility of occurrence. The disadvantages are that each malfunction is a power failure and that higher currents occur, which impedes grounding conditions for grounding conductors from the point of view for contact voltage, especially in areas with high specific soil resistance.

Analyzing trends in concepts of the neutral point grounding of transformers in MV networks in countries of the region and some European countries, it is shown that most recent attention is attracted with grounding of the neutral point through compensating coils with automatic control. In networks with a compensation coil, permanent faults are resolved with a longer delay of operation. Examples in the surrounding show that this time is about 7 s, [6]. Due to smaller currents at the fault location, the possibility to eliminate temporarily faults is left. Also, market offers special devices for quick assessment of temporarily failure location. This provides the opportunity for preventive action and to prevent transient failures becoming permanent. In addition to arc self-extinguishing, the benefits of resonant grounding are also seen in lower cost of grounding construction (due to smaller ground fault currents), less damage at the fault location and increased safety in regard to lower contact voltages.

By analyzing surge factor values, can be concluded that highest values of overvoltages were obtained at ground fault for the case of an isolated network, $k = 2.21$ p.u., and the lowest overvoltage values were obtained with the grounded neutral point through a low ohmic resistor, $k=1.78$ p.u. Because of very long line segments these differences are not too expressed.

REFERENCES

- [1] BiH Electrical Utility Company: TP-18 Technical recommendations for design and construction of grounding devices in power distribution grids and installations, Sarajevo 2002

- [2] J. Nahman: Neutral point grounding in distribution grids , Beograd: Naučna knjiga, 1980
- [3] R. Goić, D. Jakus, I. Penović: Distribution of electrical energy - internal script: Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, 2008
- [4] N. Rajaković: Analysis of electro-energetic systems I, Beograd, Akademska misao, 2002
- [5] BAS EN 50522:2011 Earthing of power installations exceeding 1 kV AC
- [6] BiH Electrical Utility Company Study, Treatment of neutral point in distribution networks JP Elektroprivreda BiH, Sarajevo, 2016
- [7] M. Kizilcay, P. La Seta: Digital simulation of fault arcs in medium-voltage distribution networks, 15th PSCC, Liege, 22-26 August 2005

BIOGRAPHY

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Zijad Bajramović was born in 1960 in Bileća, Bosnia and Herzegovina. He graduated in 1983, received his master's degree in 1986, and doctorate in 2009 from the Faculty of Electrical Engineering, University of Sarajevo. He has been employed at the Faculty of Electrical Engineering in Sarajevo as an associate professor and at Public Enterprise Electric Utility of Bosnia and Herzegovina. The area of interest is related to the testing of power equipment, analysis of stationary and transient phenomena in the power systems and electromagnetic compatibility. He is a member of IEEE, International CIGRÉ and BH K CIGRÉ.

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