Application of Matlab Tool for Analysis of Complex Grounding Systems of Overhead Power Lines

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Application of Matlab Tool for Analysis of Complex Grounding Systems of Overhead Power Lines

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Abstract – **In the paper, first it is said in general what is meant by grounding system, the need for protection as well as the consequences in case of overvoltage. The procedure for solving a complex grounding system at overhead lines is further presented, with the manner of exact modelling of a real overhead power line. In the main part, by applying the already mentioned procedure on a real example of the transmission power line Bitola - Prilep through a developed application in MATLAB, the grounding system will be solved in case of short circuit on the towers. Finally, the step and touch voltages will be presented and a conclusion will be made whether those values are within the normal range.**

Keywords – **Complex grounding systems, Touch voltage, Step Voltage, Matlab.**

I. Introduction

The grounding system of a power grid is a complex electrical circuit consisting of elements with concentrated parameters and elements with distributed parameters. The first type of elements of the grounding system include: grounding of poles of overhead power line, grounding of substations, grounding of power facilities, etc., while the second type of elements (grounding conductors with distributed parameters) include: grounding wire od overhead power lines, power cables with conductive outer sheath, steel strips and copper ropes laid in the ground, etc.

The term grounding in the power grid or in the power system means the complex of measures and assets that are taken in order to ensure conditions for normal operation of the system, safe operation and movement of people and animals near the facilities, which can come under voltage in normal or emergency conditions [1].

The paper presents the procedure for exact modeling of overhead power line and matrix solution of the voltage conditions of the grounding systems of each towers in the event of a short circuit.

The purpose of the research is to check the application of an already created tool in Matlab for analysis of complex grounding systems on overhead power lines. The test is performed on a real 110 kV overhead power line Bitola - Prilep. The results of the research are given below in the paper.

II. Modelling of Real Overhead Power Line

When it comes to the fault of the power line itself and when it is necessary to calculate the circumstances in each of its towers, the exact model of the line is applied.

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In that case, the true lengths of all spans must be taken into account, the true values of the grounding resistances at each tower, but the magnetic (inductive) coupling between the protective rope and the phase conductors will still have to be taken into account [1].

The inductive coupling is observed through the mutual impedance of the phase conductor in which the current flows to the ground connection and the protective rope. The mutual and self-impedance are calculate using Carson's equations.

An overhead line connecting two substations *p* and *q* is observed. Let the line work in a fault mode (connection of one of the phases with the ground) where the fault occurred at the span *k* ($1 < k < n$). After the injured phase from the overhead

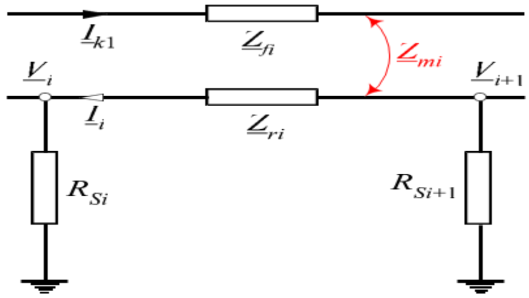

Fig. 1. View of a span of overhead power line to the left of the fault location

line to the place of the short circuit flows the currents $\underline{I}_{k1}$ and $\underline{I}_{k2}$ ($\underline{I}_{k1} + \underline{I}_{k2} = \underline{I}_Z$). The i-th span between the towers *i* and *i* + 1 is observed (Figure 1) and it is assumed that $i < k$ [1].

Due to the existence of an inductive connection between the phase conductor on which the earth fault occurred and the protective rope, the rope will induce an electromagnetic force which will act in the opposite direction to the direction of the current flow error $\underline{I}_{k1}$ in the phase conductor, that is in the direction of the current $\underline{I}_i$ (Fig.1). The individual quantities shown in Figure 1., have the following meanings [1]: $\underline{Z}fi$ - longitudinal impedance of the phase conductor of the span *i*, $\underline{Z}_{ri}$ - longitudinal impedance of the protective rope of the span i, $\underline{Z}_{mi}$ - mutual impedance between the phase conductor and the protective rope in the span i, R_{Si} - resistance of the grounding system of tower *i*, $\underline{I}_{k1}$ - current in phase conductor at short circuit flowing from substation 1 to node *k*, $\underline{I}_i$ - current in protective rope in span $_i$, $\underline{V}_i$ - potential of the tower *i*, $\underline{V}_{i+1}$ - potential of the tower *i* + 1.

According to II Kirchhoff's law, the contour of the protective earth-rope of span i, which is located between the substation *p* and the tower *k* on which the fault occurred ($i < k$), applies [1]:

$$\underline{V}_{i+1} - \underline{V}_i - \underline{Z}_{ri} \cdot \underline{I}_r + \underline{Z}_{mi} \cdot \underline{I}_{k1} = 0 \qquad (1)$$

Equation (1) allows the observed span ai to be represented more simply by phasing the phase conductor from the affected phase and the protective rope, and the existence of the mutual coupling will be accepted by inserting an equivalent voltage generator with voltage $\underline{E}_i$ (Figure 2) whose value is calculated according to the equation:

$$\underline{E}_i = \underline{Z}_{mi} \cdot \underline{I}_{k1} \tag{2}$$

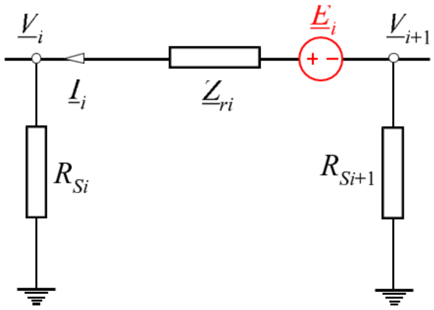

Fig. 2. Replacement circuit of a single span with equivalent voltage generator

From (1) and (2) it follows:

$$\underline{V}_{i+1} - \underline{V}_i = \underline{Z}_{ri} \cdot \underline{I}_r - \underline{E}_i = 0 \tag{3}$$

If in the diagram from Figure 2 the voltage generator is transformed into current, a new model will be obtained in which the voltage generator is equivalent to a current generator with current $\underline{J}_i$ [1].

$$\underline{J}_i = \frac{\underline{E}_i}{\underline{Z}_{ri}} = \frac{\underline{Z}_{mi} \cdot \underline{I}_{k1}}{\underline{Z}_{ri}} \tag{4}$$

This current generator can be further equated with the help of two current generators as in fig.3.

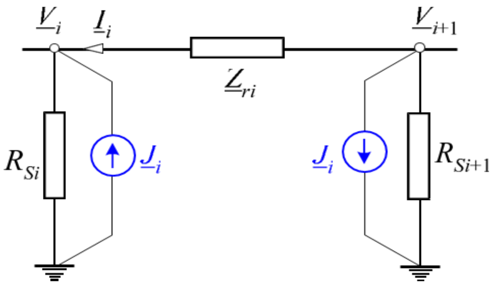

Fig.3. Replacement circuit with equivalent current generators

In this way the mutual inductance between the phase conductor and the protective rope in each span i ($i < k + 1$) is taken into account by placing two equivalent current generators at the ends of the span, according to Figure 3 with current calculated according to the expression (4). Thereby, in a node with a higher index, a current generator whose direction is negative is included, while in a node with a lower index, the current generator has a positive direction [1].

In Figure 4 all voltage generators $\underline{E}_i$, which cover the induced electromagnetic force in the protective rope of each span, are equivalent to two current generators placed left and right at the two towers containing the considered span ai. The currents of these current generators do not depend on the length of the span, but on the $\underline{Z}_{mi}/\underline{Z}_{ri}$ ratio, which is constant. In this way, in each tower place, there are two, equal in value, current generators that are placed in opposition so that they are annulled. Thus, it is obtained that the equivalent scheme of the whole line will contain only three current generators with currents $\underline{J}_p$, $\underline{J}_k$ and $\underline{J}_q$, placed in the faulted node and at the ends of the overhead line p and q. The values of these currents are calculated using the relations (5) [1].

$$\underline{J}_p = \frac{\underline{z}_m}{\underline{z}_r} \cdot \underline{I}_{k1}, \quad \underline{J}_q = \frac{\underline{z}_m}{\underline{z}_r} \cdot \underline{I}_{k2}, \quad \underline{J}_k = \left(1 - \frac{\underline{z}_m}{\underline{z}_r}\right) \cdot \underline{I}_k \tag{5}$$

Furthermore, the solution of the electrical circuit from Figure 4 can be done in various ways. Here will be shown a very simple way to solve the situation in the grounding system of the overhead line, and that is by applying matrices. The impedances $\underline{Z}_p$ and $\underline{Z}_q$ are equivalent to the grounding systems of the substations at both ends of the line.

Using the method of independent voltages (node potentials) for one electrical circuit the following matrix system of equations can be written [1]:

$$\underline{Y} \cdot \underline{U} = \underline{I} \tag{6}$$

After calculating the admittances matrix of the system, its inversion according to equation 7 gives the voltages of all grounding systems of each tower of the overhead power line [1].

$$\underline{U} = \underline{Y}^{-1} \cdot \underline{I} \tag{7}$$

III. Analysis of Grounding System of Transmission Line Bitola - Prilep in the Case of Short Circuit

In order to perform a specific analysis of the condition of the overhead line grounding system in case of short circuit, a program was developed with the help of MATLAB [6]. The

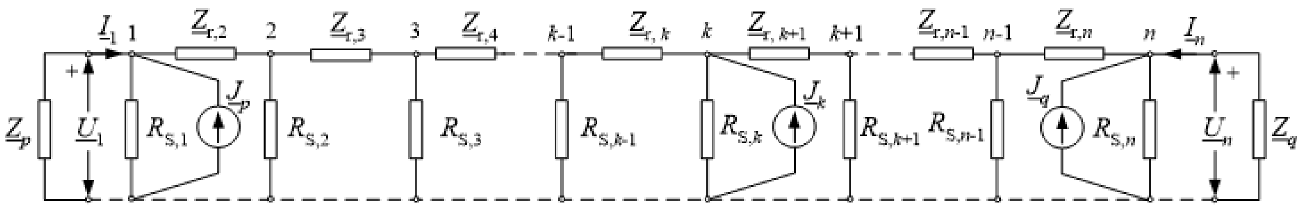

Fig.4. Equivalent scheme of the grounding system from the observed overhead line

program is developed using the equations described in Chapter 2. The interface is presented in Figure 5.

The program was developed in order to accurately solve the short-circuit conditions, so in the external .xls file data are entered on the ground resistance, the value of the actual spans, the mean geometric value of the phase conductor distances and the designed value of the typical grounding on each tower separately. Furthermore, through program code, these data are downloaded from excel and based on them, the data on the cross section, resistance and diameter of the protective rope, the number of towers of the monitored overhead line as well as the value of short circuit currents flowing left and right to the tower in near the short circuit the values of the voltages are calculated. The program gives the value of the voltage of the grounding system that is close to the short circuit as well as the rest of the voltages, which through the exported potentials get their value on each tower individually.

The main project used as a basis for the preparation of this research. Complete reconstruction of the 110 kV overhead line Bitola – Prilep is envisaged, which is located in the southwestern part of the Republic of Macedonia. Previously, the line was built with 113 concrete towers and 2 steel lattice towers. Complete removal of the towers, foundations and oat equipment and construction of a new overhead line on the same route with 125 steel lattice towers with new foundations are envisaged. The total length of the route is 33.68 km. The line is provided with high temperature conductor type Z - shaped AAAC Z - shape 324 mm^2 and protective optical rope type OPGW-12G652 + 12G655-2S-113 112.3 mm^2 [4].

Short circuit current calculations are made in NEPLAN 5.5.3.[2][5]. Exactly at the place where the tower is located, that is its stationary entered in percentage that will be the total short circuit current. Furthermore, with the procedure of current divider, the data for the currents flowing left and right towards the place of fault were obtained. The results are presented in Table I.

TABLE I
SHORT CIRCUIT CURRENTS NEAR THE POLES

Number of the tower	Single phase short circuit current (kA)		
	total	left of the tower	right of the tower
1	11.530	11.471	0.058
34	7.680	5.610	2.069
72	6.078	2.514	3.564
107	5.773	0.825	4947
125	5.829	0.009	5.820

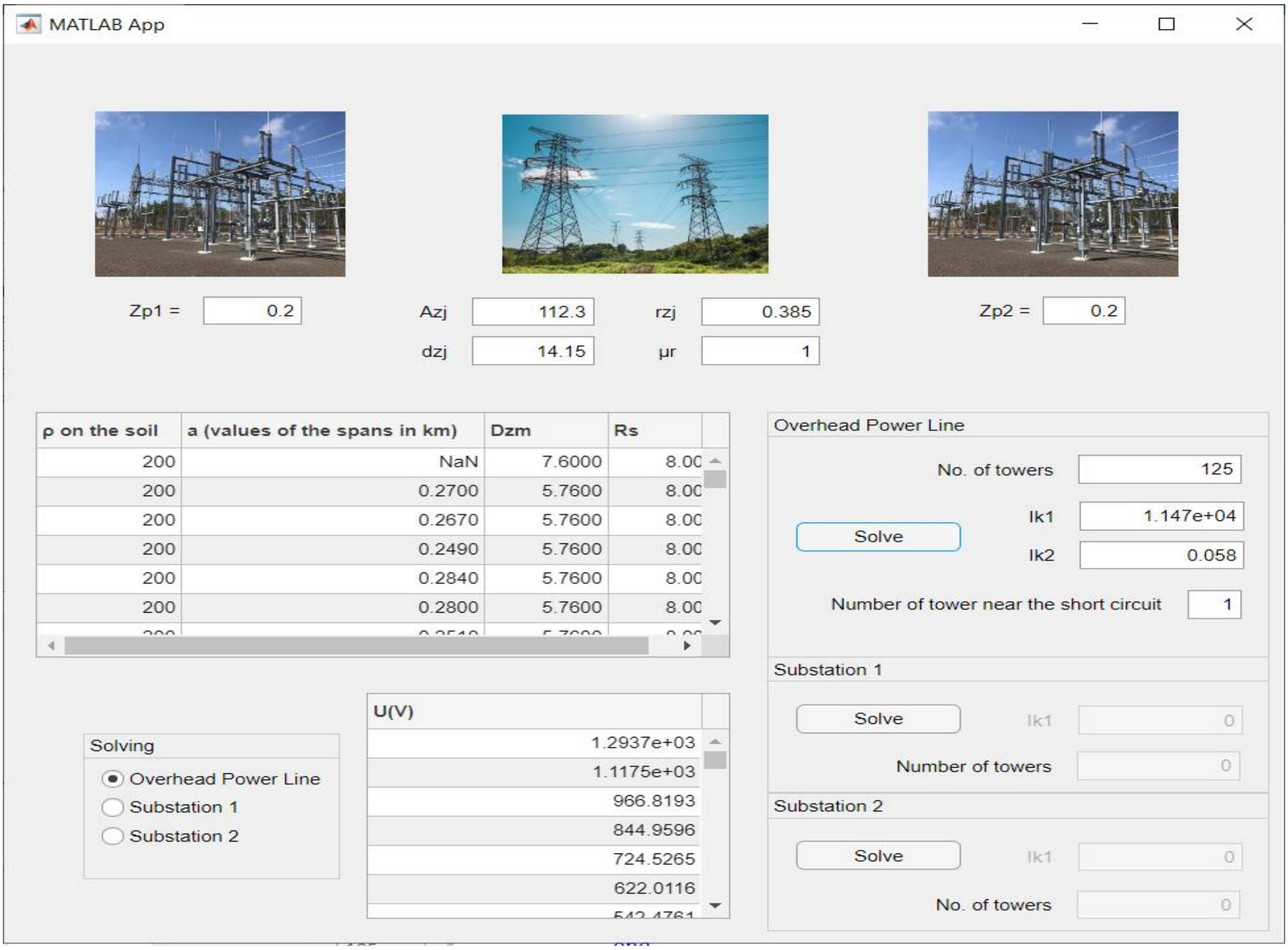

Fig.5. Interface of matlab tool for resolving voltages of the grounding system from the overhead line in case of short circuit

Using the calculated values from table I and the values from the technical data for the conductor and the protective rope are calculated the voltage of the towers. The calculated value is 1.29 kV, in case of short circuit near the tower with number 1. The other values respectively for the towers with ordinal number 34, 72, 107 and 125 are calculated and entered in Table II.

TABLE II
SHORT CIRCUIT CURRENTS NEAR THE TOWERS

Number of tower	Voltage U(kV)
1	1.293
34	3.472
72	2.570
107	2.232
125	0.386

The calculation of maximum touch and step voltages is based on the calculated potential differences calculated with a program developed in excel [1]. The foundation data are used from [4], for each foundation separately. Because the transmission line towers with ordinal numbers 1, 34, 72, 107 and 125 are considered for each tower according to [3] [4] there are different dimensions of the foundation and different value for the ground resistance. The values of the results are shown in Table III.

TABLE III
MAXIMUM POTENTIAL DIFFERENCES OF TOUCH AND STEP

Number of tower	Voltage(kV)	Ed_{max}(%)	Ec_{max}(%)
1	1.293	30.86	18.90
34	3.472	22.16	22.20
72	2.570	14.48	21.40
107	2.232	22.91	20.00
125	0.386	29.37	18.7

The maximum values of the touch and step voltages are further calculated according to the equations below, and the corresponding values are entered in Table IV.

$$U_{d\max} = \frac{Ed\max(\%)}{100} \cdot \frac{Uz}{Sd} \qquad (8)$$

$$U_{c\max} = \frac{Ec\max(\%)}{100} \cdot \frac{Uz}{Sc} \qquad (9)$$

From the values in the table IV it can be concluded that the end towers are not very critical. Near those towers are the substations, so the short circuit that occurs part of its value is taken to the ground through the network grounding of the substations and all elements such as overhead lines and cable lines that are connected to the grounding network. The operating time of the switches is 0.1s. According to the diagram in Figure 6 [1], all the values that are analyzed are within the allowed limits, the most critical is the value of the tower 34. If the value of the grounding of the tower 34 would be above the allowable, then measures should be taken to improve the grounding.

TABLE IV
MAXIMUM VALUES OF TOUCH AND STEP VOLTAGES

Number of tower	Voltage U(kV)	Ud_{max} (V)	Uc_{max} (V)
1	1.293	306.9	111
34	3.472	669	481.7
72	2.570	323.5	343.7
107	2.232	393.34	202.9
125	0.386	87.2	32.8

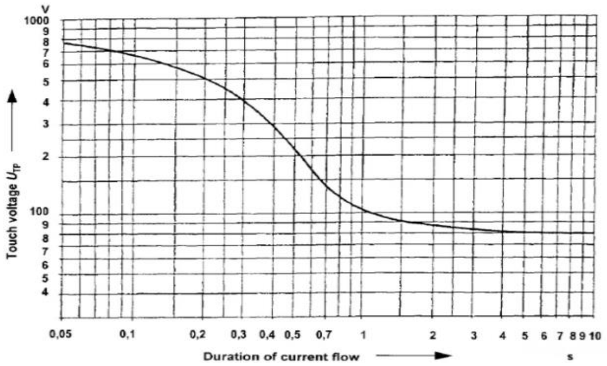

Fig.6. Permissible values of touch voltage (V) according HD637 depending on the duration of short circuit

IV. CONCLUSION

The paper presents how with the help of an application developed in MATLAB the conditions of the overhead line grounding system that connects two substations can be solved. In the research, the emphasis is on the 110 kV overhead power line Bitola - Prilep. Short circuit currents are calculated with NEPLAN, and further with the application the voltages are calculated. From the results, it can be concluded that all the values are within the allowed limits, and the goal is to show how in a fast way with a software tool all the values are calculated.

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