Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 100 (2015) 1515 – 1521
Procedia Engineering
www.elsevier.com/locate/procedia

25th DAAAM International Symposium on Intelligent Manufacturing and Automation, DAAAM 2014

Universal Mathematical Model of Leakage Currents and Currents Spread on Elements of High-Voltage Pillar

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Abstract

In this paper was developed scheme of distribution of leakage currents and currents spread over high-voltage pillar. Created its mathematical model. Model of distribution leakage currents and spreading represented as circuits containing voltage source and resistance. Using Kirchhoff's laws and method of circuit currents helped form the equations for each circuit. The model is designed to calculate the parameters of the cathodic protection of high-voltage pillar.

Peer-review under responsibility of DAAAM International Vienna

Keywords: high-voltage lines; high voltage; electrochemical corrosion; equivalent circuit; pillar

1. Main text

The length of the high-voltage lines (overhead lines) in the Republic of Kazakhstan exceeds 23 thousand kilometres, and most of them lies outside the settlements. Any accident at 110-500 kV overhead lines associated with the breakdown of the insulation, continuity of current-carrying wires, towers fall, leading to disruption of power supply for whole regions of the country.

Due to the drift of ions in the soil caused by leakage and electromagnetic fields of power lines electrochemical corrosion processes appear that leads to active degradation of the metal and concrete, and accordingly the elements

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Peer-review under responsibility of DAAAM International Vienna
doi:10.1016/j.proeng.2015.01.523

of high-voltage power lines. The effect of electrochemical corrosion is described as equations electrochemical reactions.

One of the major causes of electrochemical corrosion is the character and magnitude of leakage currents on the elements of pillar and current spreading in the soil caused by the induced electromagnetic fields.

Analyzed the work of M.I. Mihailov, L.D. Razumov., S.A. Sokolov [1,2,5] on the influence of high voltage lines to underground pipelines and facilities of communication, as well as the corrosion of metals exposed to alternating currents.

Similarly analyzed works M.A. Tolstaya., E.I. Ioffy., I.V. Potemkinskaya about the impact of the AC power frequency on electrocorrosion steel and ways of combating it [3,4].

In the work of A.A. Zakharov, V.V. Popov, S.V. Nikolashkin provides principles for the development of mathematical models and recommendations for the safe operation of 110 kV at the site "Yakutsk-Churapcha-Khandyga" [6].

In paper Marin D. Palii L., Samoilescu G., Nicolaie S., Nedelcu A., Ilie C., Popa M. A theoretical model and the program on the numerical determination of the electromagnetic and thermal phenomena on power lines [7].

The analysis did not reveal the presence of models describing the effect of leakage currents and spreading to the structural elements of high-voltage power lines.

To develop the model we use the classical methods of theoretical foundations of electrical [8,9]. The advantage of these methods is their versatility, they can therefore be used for any support structure.

2. Development of mathematical model

Consider the design of a pillar type PB - 500 (Figure 1).

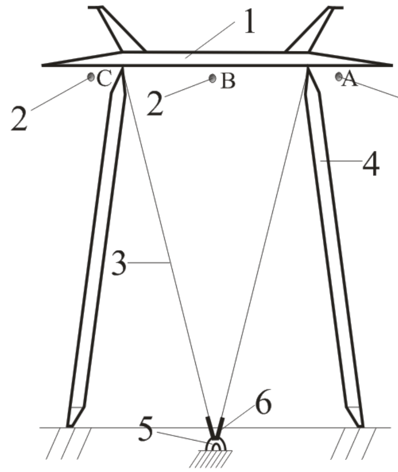

Fig. 1. The construction of a pillar type PB - 500, where 1 - traverse, 2 - wire phase 3 - quickdraw, 4 - rack, 5 - anchor bolt 6 - U-bolt.

Pillar power line portal type with hinged of foundations and traverse racks and handed down from the plane of the portal quickdraws. Racks and quickdraws are either metal girders or hollow concrete pipes. Quickdraws performed or a flexible steel cable, or of the circular low alloy steel. Quickdraws supports high-voltage power lines - 500 are made of two flexible steel cables twisted together.

Figure 2 shows the equivalent circuit [10] of the type of support PB - 500, combined with the image of the tower structure.

For the considered application is the most suitable method of loop currents [7,8]. In the generalized model, made on the basis of this method is simple enough to implement its decomposition into elementary contours distribution of leakage currents and elements of support and current spreading in the soil that provides the visibility of the model.

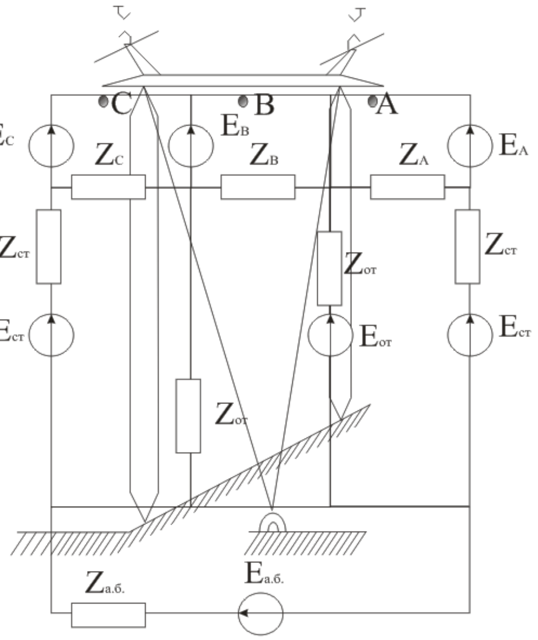

Fig. 2. The approximate equivalent circuit pillar PB-500.

Where:

E_A, E_B E_C, respectively, consists of:

•
• electromotive force generated by the electromagnetic fields [11] in the flow of currents in phases A B, C.
$E_{ст}$ - electromotive force generated by the electromagnetic field between the wires and ground.
$E_{от}$ - electromotive force created by the electromagnetic field between the wires and the U bolt.
$E_{а.б.}$ - electromotive force created by all electromagnetic fields acting on the elements of pillar;
Z_A - air resistance of phase A;
Z_B - air resistance of phase B;
Z_C - air resistance of phase C.

$Z_{ст}$ consists of:

• resistance of reinforced concrete rack
• capacitive reactance between the ground and traverse

$Z_{от}$ consists of:

• resistance of the metal quickdraw
• resistance of the metal U-bolt
• capacitive reactance between the ground and traverse

$Z_{а.б.}$ consists of:

• resistance of the metal anchor bolt
• resistance of reinforced concrete slab pillar mounting in the ground

• resistance of the soil

This model does not include all the air resistance of the circuit, derived from the phase because of their large sizes.

Thus, we obtain the equivalent circuit of the pillar (Figure 3).

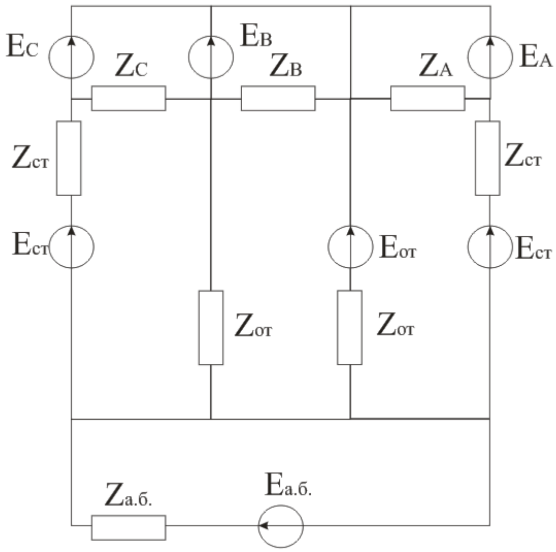

Fig. 3. Equivalent circuit pillar PB-500.

Arbitrarily we arrange directions of the currents in the circuit branches, take the direction of bypass circuits, denoted nodes (Figure 4).

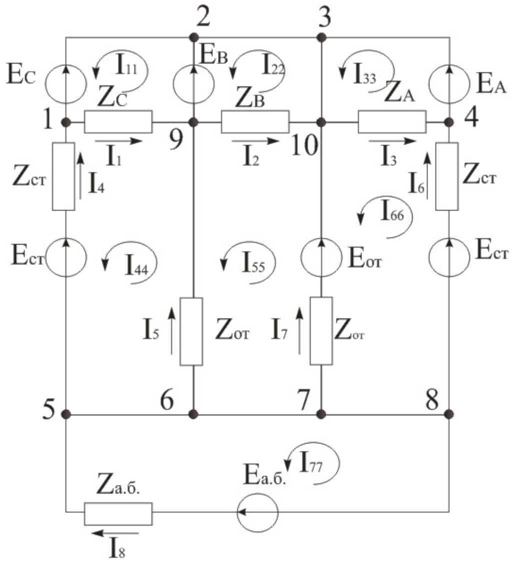

Fig. 4. The alignment of the currents of the equivalent circuit.

To obtain the system of equations under the laws of Kirchhoff formulations of the first law equation for the nodes:

First node $I_4 - I_1 = 0$
Second node $I_1 + I_2 = 0$
Third node $I_2 + I_3 = 0$
Fourth node $I_3 + I_6 = 0$
Fifth node $I_8 + I_4 = 0$
Sixth node $I_7 - I_5 = 0$
Seventh node - no equation
Eighth node $-I_6 - I_7 = 0$
Ninth node $I_1 + I_5 + I_2 = 0$
Tenth node $I_2 - I_3 + I_6 = 0$

On the second Kirchhoff's law form the equations for contours 11-77:

Contour 11: $-E_C = I_1 \cdot Z_C$
Contour 22: $-E_B = I_2 \cdot Z_B$
Contour 33: $E_A = I_3 \cdot Z_C$
Contour 44: $-E_{CT} = -I_4 \cdot Z_{CT} - I_1 \cdot Z_C + I_5 \cdot Z_{OT}$
Contour 55: $E_{OT} = -I_5 \cdot Z_{OT} - I_2 \cdot Z_B$
Contour 66: $E_{CT} = I_6 \cdot Z_{CT} - I_3 \cdot Z_C$
Contour 77: $-E_{a.b.} = -I_8 \cdot Z_{a.b.}$

The total resistance of the circuit is called a proper loop resistance (1-7):

$$Z_{11} = Z_C\ ; \quad (1)$$
$$Z_{22} = Z_B ; \quad (2)$$
$$Z_{33} = Z_A ; \quad (3)$$
$$Z_{44} = Z_{CT} + Z_C + Z_{OT} ; \quad (4)$$
$$Z_{55} = 2Z_{OT} + Z_B ; \quad (5)$$
$$Z_{66} = Z_{CT} + Z_A + Z_{OT} ; \quad (6)$$
$$Z_{77} = Z_{a.b.} ; \quad (7)$$

As well write the common contours of resistance - resistance branches adjacent two contours (8-12):

$$Z_{14} = Z_{41} = -Z_C ; \quad (8)$$
$$Z_{25} = Z_{52} = -Z_B ; \quad (9)$$
$$Z_{36} = Z_{63} = -Z_A ; \quad (10)$$
$$Z_{45} = Z_{54} = -Z_{OT} ; \quad (11)$$
$$Z_{56} = Z_{65} = -Z_{OT} ; \quad (12)$$

The rest of the common resistance of zero.

Thus, we obtain a system of equations describing the equivalent circuit for currents (13):

$$\begin{cases} I_4 - I_1 = 0, \\ I_1 + I_2 = 0, \\ I_2 + I_3 = 0, \\ I_3 + I_6 = 0, \\ I_7 + I_4 = 0, \\ I_7 - I_5 = 0, \\ -I_6 - I_7 = 0, \\ I_1 + I_5 + I_2 = 0, \\ I_2 - I_3 + I_6 = 0; \end{cases} \tag{13}$$

And for the electromotive forces (14-20):

$$Z_{11} \cdot I_{11} + Z_{12} \cdot I_{11} + Z_{13} \cdot I_{11} + Z_{14} \cdot I_{11} + Z_{15} \cdot I_{11} + Z_{16} \cdot I_{11} + Z_{17} \cdot I_{11} = E_C, \tag{14}$$
$$Z_{21} \cdot I_{11} + Z_{22} \cdot I_{11} + Z_{23} \cdot I_{11} + Z_{24} \cdot I_{11} + Z_{25} \cdot I_{11} + Z_{26} \cdot I_{11} + Z_{27} \cdot I_{11} = E_B, \tag{15}$$
$$Z_{31} \cdot I_{11} + Z_{32} \cdot I_{11} + Z_{33} \cdot I_{11} + Z_{34} \cdot I_{11} + Z_{35} \cdot I_{11} + Z_{36} \cdot I_{11} + Z_{37} \cdot I_{11} = E_A, \tag{16}$$
$$Z_{41} \cdot I_{11} + Z_{42} \cdot I_{11} + Z_{43} \cdot I_{11} + Z_{44} \cdot I_{11} + Z_{45} \cdot I_{11} + Z_{46} \cdot I_{11} + Z_{47} \cdot I_{11} = E_{CT}, \tag{17}$$
$$Z_{51} \cdot I_{11} + Z_{52} \cdot I_{11} + Z_{53} \cdot I_{11} + Z_{54} \cdot I_{11} + Z_{55} \cdot I_{11} + Z_{56} \cdot I_{11} + Z_{57} \cdot I_{11} = E_{OT}, \tag{18}$$
$$Z_{61} \cdot I_{11} + Z_{62} \cdot I_{11} + Z_{63} \cdot I_{11} + Z_{64} \cdot I_{11} + Z_{65} \cdot I_{11} + Z_{66} \cdot I_{11} + Z_{67} \cdot I_{11} = E_{CT}, \tag{19}$$
$$Z_{71} \cdot I_{11} + Z_{72} \cdot I_{11} + Z_{73} \cdot I_{11} + Z_{74} \cdot I_{11} + Z_{75} \cdot I_{11} + Z_{76} \cdot I_{11} + Z_{77} \cdot I_{11} = E_{a.b.} \tag{20}$$

Conclusion

The lack of mathematical models of the distribution of leakage currents and currents spreading does not allow the analysis of states subject to electrochemical corrosion elements of designs of high-voltage pillars.

In developing the model used methods of theoretical electrical.

Developed universally model allows us to describe character and values the leakage current on all elements of the pillar; interaction of leakage currents and currents spreading in the soil; identify the most vulnerable elements of pillar, subject to electrochemical corrosion; develop recommendations for changes to the design of pillar to minimize leakage currents; calculate the necessary parameters for cathodic protection.

Any design of pillars high-voltage can be described by a similar model.

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