Regular paper

INFLUENCE OF UNCOATED AND PLASTIC COATED METALLIC SHEATHED CABLES ON THE DISTRIBUTION OF THE ELECTRIC POTENTIALS IN URBAN AREA NEAR HIGH VOLTAGE SUBSTATIONS

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Abstract: In the cases when ground faults occur, the ground potential tends to rise around high voltage substations. This effect has the potential to cause dangerous voltages between telephone subscriber lines and local ground. In this paper, using a computer model of the substation grounding system together with all of the connected uncoated and plastic coated metallic sheathed cables, an attempt to do an estimation of the ground potential rise zone of influence on the subscription telecommunication installations in urban environment is presented. Also, the effect of the equalizing of potentials by other buried metallic networks, which is very typical for the urban environment, is included in the model by the means of measured potentials in a number of specified points.

Keywords: Uncoated metallic sheathed cables, High voltage substations, Urban areas, Ground rise potential, Telecommunication installations

INTRODUCTION

The ground potential rise (GPR) in high voltage substations, in case of ground faults, may cause dangerous voltages between telecommunication installations and local ground. According to the CCITT directives [1], there is a definition of a 430 V contour that is set up to be the border of the zone of ground potential rise influence on the telecommunication installation. This means that all wire-line telephone subscriber installations inside the defined zone have to be protected.

When dealing with high voltage substations that are located outside an urban area, the shapes of the equipotential contours usually follow the form of the grounding system. At larger distances the equipotential contours tend to become circles. Typically the ground potential value decays very fast in radial direction, especially far from the zone of the substation. However, when we are dealing with high voltage substations that are located in urban areas, the grounding system of the high voltage substation is often connected to a buried network of uncoated metallic sheathed cables. Although such types of cables are no longer manufactured in many countries, many of them are still in operation, especially in the undeveloped countries. Also, very often there are other buried metallic structures located close to the substation grounding system. These structures are extended through out the urban area, and in this category are metal sheaths of telecommunication and power cables, neutral wires of power distribution lines, water pipes, pipelines for heating and gas, rails of traffic systems. It has been shown [2,3,4] that metallic networks directly connected to the substation grounding system substantially affect the ground potential rise zone of influence. This is especially the case of urban areas filled with different types of cables closely positioned to the high voltage substations. However, all of the elements of the urban environment that affect the potential distribution cannot be included in any model. This is the case firstly, because of the complexity of the problem, and, secondly, because there are numerous unknown elements of the urban environment in question.

Results of calculations that confirm this conclusion in a zone near the substation are presented. Also, it is noted that at a distance, especially in the highly urbanized zone, the additional buried networks of conductors tend to equalize potentials. The level of such equalizing of the potentials has to be determined experimentally [5,6]. This equalizing effect is included in the computer model by forcing the model to accept equalizing of potentials in extent determined by measurements in a small number of points.

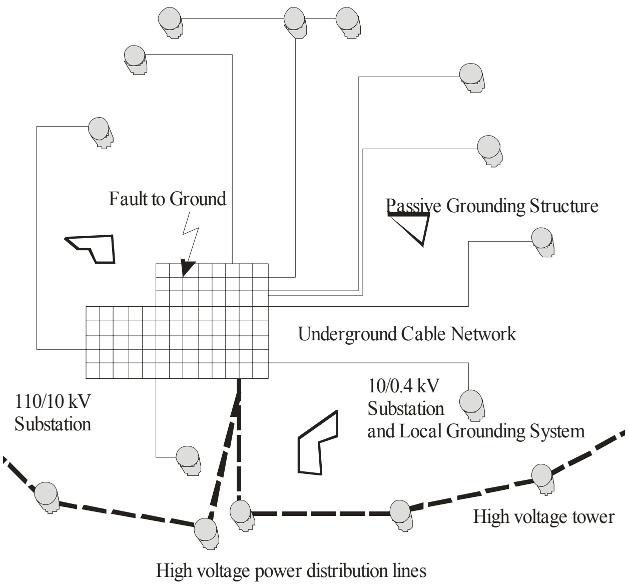

Fig. 1 - *Grounding system of high voltage substation connected to underground cable network*

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MODEL OF THE GROUNDING SYSTEM CONNECTED TO AN UNDERGROUND CABLE NETWORK

On Fig. 1 an illustration of the model of a substation grounding system connected to an underground cable network is given. The given model is based on the following assumptions [2,7,8]. The grounding electrodes are modeled as a set of connected conductors buried in homogeneous or two-layer soil. The uncoated metallic cable sheaths are directly connected to the grounding conductors and are also connected to 10/0.4 kV local substations or to other cables.

Also, plastic coated cables are taken into consideration represented with resistance proportional to the length and characteristics of the cable, which is connected between two substations. The tower of high voltage power distribution line is also represented using rod grounding system at the tower position, and resistance, placed between two towers or between the tower and the high voltage substation, proportional to the length of the protection wire and its electrical characteristics.

The grounding electrodes are divided into n_g segments, and the cables are divided in n_c segments. The cables are considered to have a longitudinal impedance, with equivalent circuit that is illustrated in Fig. 2 [7,8].

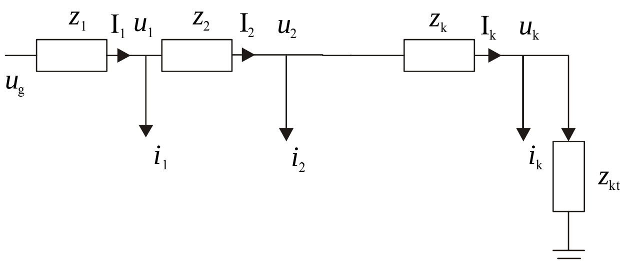

Fig. 2 - *Equivalent circuit of the uncoated metallic sheathed cable*

The parameters y_k denote the longitudinal admittance of cable k sheat segment. Also, i_a denotes the current emanating to the soil from sheat segment A, while l_k denotes current flowing through sheat segment k.

The potential of the source substation is u_g, while u_k is the potential of the sheat segment k. The consumer substation grounding system is denoted by the admittance y_{kl}. The parameters needed for the circuit in Fig. 2 are obtained using measured data for given types of cables which can be found elsewhere [2].

For this model of a cable, the following relation can be written:

$$-i_k = Y_{gk} \cdot u_g + Y_k \cdot u_k \tag{1}$$

where

$$Y_{gk} \equiv \left[-y_k \, 0 \ldots 0\right]^t , \tag{2}$$

and

$$Y_k \equiv \begin{bmatrix} 2y_k & -y_k & 0 & \ldots & 0 \\ -y_k & 2y_k & -y_k & \ldots & 0 \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ 0 & 0 & \ldots & -y_k & y_k + y_{kt} \end{bmatrix} . \tag{3}$$

Relation (1) is applicable for all cables which are emanating from the source substation if the specific values for the parameters y_k and y_{kt} are used.

Consequently, based upon (1), the following general equation, including all radial positioned cables, can be written as:

$$-i_c = Y_g \cdot u_g + Y_c \cdot u_c \tag{4}$$

where

$$i_c \equiv \left[i_1^t \ \ldots \ i_m^t \right]^t , \quad u_c \equiv \left[u_1^t \ \ldots \ u_m^t \right]^t \tag{5}$$

$$Y_g \equiv \left[Y_{g1}^t \ \ldots \ Y_{gm}^t \right]^t , \quad Y_c \equiv diag\{Y_k\} . \tag{6}$$

When we have a complex cable configuration, the matrix Y_c is not diagonal, and the form it takes is in relationship, that is, has to correspond to the mutual cable connections.

The previous equations imply that there is no mutual magnetic coupling between cable segments. In practical cases, such an assumption holds for the uncoated, steel armored lead sheathed three-phase cables that are commonly used in distribution systems. For unarmored cable constructions with uncoated metal sheaths the expressions given with (6) are approximate.

Voltages u_c depend on the currents flowing from cable sheath segments and from the source substation ground electrode into the soil. This relationship can be expressed as:

$$u_c = R_{gc} \cdot i_g + R_{cc} \cdot i_c . \tag{7}$$

When considering the source substation ground, the analogous relation for the electrode would be:

$$1_g \cdot u_g = R_{gg} \cdot i_g + R_{gc}^t \cdot i_c . \tag{8}$$

From the current continuity law it follows that

$$1_g^t \cdot i_g + 1_c^t \cdot i_c = J \tag{9}$$

If we substitute u_c from (7) into (4), the following relationship can be obtained

$$Y_c \cdot R_{gc} \cdot i_g + \left(Y_c \cdot R_{cc} + E\right) \cdot i_c + Y_g \cdot u_g = 0 \tag{10}$$

Relations (8)-(10) build a closed system of linear equations that can be solved for i_g, i_c and U_k. This closed system of linear equations is the basis of the computer model.

In order to be able to represent a real life situation of the terrain layout, the positioning of the high voltage substation and the surrounding networks of telecommunication lines, water pipelines and other types of uncoated metallic sheathed cables is needed.

In limiting conditions when no digital data for positioning existed, the positioning of all relevant elements was supplied for the computation model in the manner of position coordinates obtained by the means of digitized data recovered from hard copy maps of all the needed different types of lines. The hard copy maps where transformed into digital images, which are afterwards enhanced using the CorelDraw software package. The necessary information is held in a separate layer of the image and than exported into a special file format, which can be relatively easily exploited in the following computational steps.

POTENTIAL DISTRIBUTION AROUND 110/10 KV SUBSTATION PLACED IN URBAN AREAS

The created computer model is afterwards used for estimation of the ground potential rise zone of influence around an existing 110/10 kV substation in case of a ground fault.

The model is practically used for the network of 10 kV buried uncoated metallic sheathed cables (IPO13 or IPO13A) and plastic coated cables (XHP48) in a 4000 x 3500 m^2 area with soil resistivity of ρ=273 Ωm and current fault 15300 A, which is illustrated on Fig. 3. The substation's surrounding is such that it enters a highly urbanized area on the upper side (Fig. 3), while it is also a part of a partially urbanized area on the lower side (Fig. 3). Each substation has a local grounding system modeled like a rod with a given diameter and length.

In order to verify the findings detailed measurements were also made. The measurements were performed using the current injection method, while following the procedures that are given in [6].

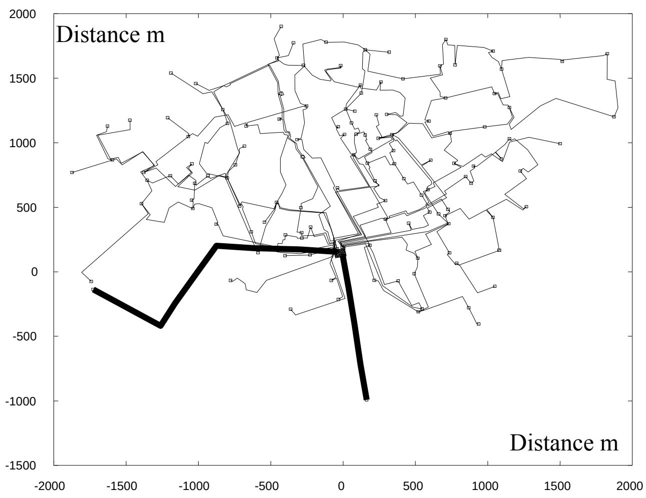

Fig. 3 - *Grounding system connected to cable network of existing 110/10 kV substation in urban area*

The results of the calculated values of the potential distribution around the high voltage substation are given in Fig. 4. It can be seen that around the substation a separation of two areas can be done. On the upper side in Fig. 4, the highly urbanized area that includes complex underground network of water pipes, pipelines for heating, metallic sheathed cables for telecommunication and power, local grounding and other buried metallic structures, produces equalizing of the potential at a given distance of the substation. The same effect can not be seen on the lower side in Fig. 4 where we have a partially urban area. These results are also in accordance with similar results already reported in [5,6].

Fig. 5 shows the calculated equipotential lines around the high voltage substation together with the equipotential line representing the border of the ground potential rise zone according to the CCITT directives.

It can be concluded that the protection of the subscriber telecommunication installation based on the concept of the ground potential rise zone of influence is not always applicable in the highly urbanized areas, where potentials may become equalized due to large underground networks of conductors. In such cases the protection should be based on the potential difference that may cause overvoltages in the telecommunication lines.

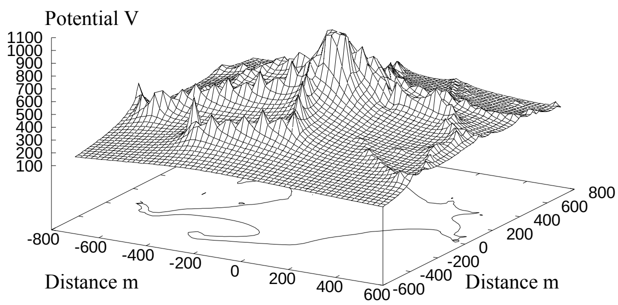

Fig. 4 - *Calculated values of the potential distribution around the 110/10 kV substation*

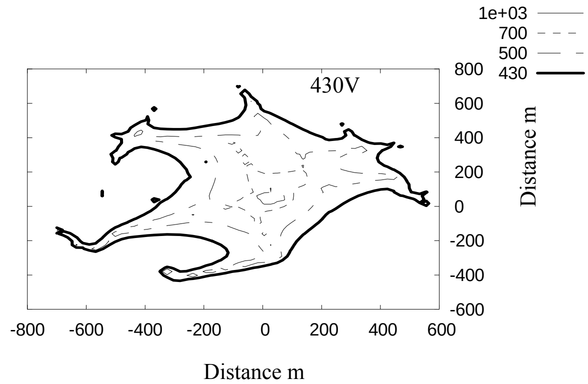

Fig. 5 - *Calculated equipotential lines around the 110/10 kV substation and the limit according to the CCITT directives*

CONCLUSION

When the grounding system of a high voltage substation is connected to uncoated metallic shielded cables, the uncoated cables act as a part of the grounding system and, thus, have large influence on the potential distribution around the substation.

National and international regulations define the potential contour of 430 V as a border of the ground potential rise zone of influence on telecommunication installations in the cases of faults to ground inside a high voltage substation or on a connected power line.

However, if the substation is in a highly urbanized area, the potentials are equalized due to large and complex underground metallic interconnected networks.

In order to observe the ground potential rise zone of influence in such cases, a computer model of the substation grounding system and all connected uncoated metallic sheathed cables has been developed. Using this model, in this paper an estimation of the zone of influence of ground potential rise transferred to the consumer installations in urban environment has been presented. The effect of the equalizing of potentials by other buried metallic networks close to the substation, which is typical for highly urban environments, is included in the model by the means of measured values of the potentials for a small number of specified points.

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