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Transfer characteristics of electric-power lines passing through urban and suburban areas

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ABSTRACT

Distribution systems consist of single-phase, two-phase, and/or untransposed three-phase lines serving unbalanced loads. Because of that during normal operating conditions of a distribution line, unbalanced currents flow through the ground and neutral conductor(s). Also, a fluctuating magnetic field exists around and along the line and it interacts with the surrounding metal installations. Currents induced in these installations reduce the part of the current returning through the ground and neutral line conductor(s). Thus, for determination of the actual values of series impedance of distribution lines it is necessary to take into account the existence of surrounding metal installations. Independent of their basic function, these installations spontaneously form a large network of different mutually connected elements that are in direct or indirect contact with earth. Also, this network is mainly under the surface of the earth and it has structure and topology that cannot be visually determined or verified. However, from the standpoint of the influence on distribution line parameters all these, known and unknown, metal installations can be substituted by only one equivalent conductor. The favorable effects of this conductor on the series impedance of different types of distribution lines are evaluated.

1. Introduction

Distribution networks that supply modern urban agglomerations with electrical energy contain, inter alias, a large number of HV (high voltage) and MV (medium voltage) lines passing through urban and suburban areas. Urban surroundings of these lines represent their particularity relevant for their transfer characteristics. However, the favorable effects emanating from such surroundings have not been so far taken into account on the occasion of determination of transfer characteristics of this type of electric-power lines. None of the existing methods enables solving this problem that has practically appeared from the very beginning of the application of Tesla's alternative poly-phase currents in the contemporary world. The increasing size of modern distribution networks as well as the higher operating and short-circuit currents of these networks have been matched by over-spreading networks of earth return circuits (different pipelines, different cables, overhead line neutrals, etc.) close to HV and MV distribution lines. Space dispositions of all of these installations, determined mainly by dispositions of city streets, and small mutual distances result in an inductive and, in the vicinity of substations, conductive coupling of the two network types.

The usage of common routes (mainly street pavements) for various supply networks (electricity, water, gas, oil, telecommunications, etc.) unavoidably leads to the appearance of the problem of mutual influence of these installations. Because of that, a great attention was paid in the past to the problem of a harmful and dangerous influence of the power installations on different types of installations that can be exposed to this influence (for example: [4]).

No less attention was devoted in the past to the other aspect of the considered phenomena, i.e., to the problem of determination of ground fault distribution between soil and neutral conductors (for example: [5,6]). However, the problem of determination of the influence of metal installations surrounding a feeding distribution line on ground fault current distribution through the grounding system of a supplied substation is considered and for the first time solved in [1]. The solution is achieved by introducing one fictitious conductor of cylindrical form placed around and along with the feeding cable-line through which flows the ground fault current. Somewhat later, the achieved solution is extended to include overhead distribution lines [2]. It is the only so far developed method for determination of the ground fault current fraction induced in the urban and suburban metal installations surrounding a distribution feeding line and a realistic value of the ground fault current fraction that, in urban conditions, flows only through the earth.

The investigation results presented in [1,2] show that part of the ground fault current flowing through the earth, in typically urban environments, is three to five times smaller than it has been considered earlier. This fact throws completely new light on the whole grounding problem of urban HV/MV substations and dramatically changes our perception about the magnitude of this

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problem. Now it can be seen within a realistic framework that, in general, leads to the more economical solutions.

The solution obtained in [1] simultaneously gives possibility for solving another quite different, but, from the standpoint of efficient power delivery, very significant problem. This is the problem of determination of the distribution line series-impedance parameters without ignoring the surrounding metal installations. Namely, on the basis of the imagined physical appearance of the introduced fictitious conductor, it is obvious that this conductor acts as an additional neutral conductor of each distribution line passing through urban and suburban areas.

An additional neutral conductor representing the surrounding metal installations certainly improves transfer characteristics of distribution lines, but its relevant parameters depend on many local factors and should be determined separately in each specific case. Because of that, it is not possible obtain a complete insight into its effects in all practically possible situations. According to this, a quantitative analysis presented in this paper has only the aim of pointing out at the magnitudes of these effects that can be anticipated in the cases of an average degree of urbanization. The effects are separately considered from the standpoint of different types of distribution lines (single-phase, two-phase, and untransposed three-phase lines, either as cable or overhead lines), as well as from the standpoint of the degree of urbanization of the area through which the line passes. The results of the performed quantitative analysis show that the relative improvement of the line transfer capacity, for the considered cable lines, is between 2.87% and 4.81% under the conditions that can be considered as average from the standpoint of urbanization level. Under the identical urban conditions, for the considered overhead lines the improvement is significantly greater, or: between 10.18% and 16.41%. Also, the performed quantitative analysis shows that in considered urban conditions the lost neutral conductor of the underground single-phase cable line (due to corrosion for example) is completely substituted with surrounding metal installations and there is no need for a new one. Additionally, the performed quantitative analysis points out at the possibility of using significantly smaller cross-sections for the neutral conductors of all considered overhead lines. Finally, the performed quantitative analysis shows that electrical energy losses in distribution lines are significantly smaller than it was considered in the past.

The objective of this paper is to present the only so far developed method for correct determination of series-impedances of power lines passing through urban and suburban areas. The presented method allows a significantly greater utilization of the existing and more economical construction of the new HV and MV distribution lines. All of these certainly lead to a more efficient delivery of electrical energy through distribution networks. These networks represent the most expensive infrastructure in all modern towns and their value in a large megalopolis of the contemporary world is estimated to be of the order of several tens of billions of dollars. Thus, seen on the global level, the economical effects that can be achieved by application of the presented method are enormous.

2. Basic problem description

Under normal operating conditions, instead of the ground fault current, an unbalanced current flows through the earth and return circuits, including the surrounding metal installations. Its value is certainly significantly smaller, but its relative distribution between the earth and return circuits remains the same as in the case of a ground fault current. This current appears as a consequence of the fact that distribution systems consist of single-phase, two-phase, and/or un-transposed three-phase lines serving unbalanced loads. Thus, for determination of the line-series-impedances it is necessary to retain the identities of the self and mutual impedance terms of conductors and take into account the return paths for unbalanced currents. According to this, the actual values of the line series-impedance parameters can be obtained by using the well known calculation procedure presented in e.g., [8], just when the relevant parameters of the mentioned fictitious conductor are determined for a certain distribution line.

According to the current engineering practice, the existence of surrounding metal installations is completely disregarded in the calculation procedure of determination of the value of series-impedance of an electric-power line passing through urban or suburban areas, e.g., [8]. Thus, the problem to be solved can in brief be defined in the following manner: How to take into account the actual situation, i.e., the existence of surrounding metal installations?

The analytical expressions necessary for conductively and inductively coupled electrical circuits having common return path through the earth, have been known for a long time [3]. They have been derived under the assumption that the power line is laid in a homogeneous soil of a resistivity equal to the equivalent resistivity of the normally heterogeneous (multilayer with each layer having a different resistivity) soil. Thus, it can be said that the problem of determination of distribution line series-impedance has been in principle solvable for a long time. However, it was not sufficient because of practical difficulties, i.e., because of many uncertain or unknown relevant data about the actual electrical circuits.

Many metallic structures of different basic functions are situated underground, like: sheaths of different cable lines, neutral conductors of the low voltage network, steel water pipes, building foundations, etc. Some of them are not in direct contact with the earth, while the others are in an effective and continuous contact with the earth. They are interconnected and their spatial disposition is different in each particular case and changes along any of the distribution lines. Also most of them are laid under the pavements of the streets and many relevant data about them cannot be visually determined or verified.

Grounding system of a distribution HV/MV substation consists of the substation grounding electrode and many outgoing MV cable lines acting as external grounding electrodes, and/or conductive connections with the grounding systems of the supplied MV/LV substations [7]. The spontaneously formed grounding system involves a large urban area around a HV/MV substation. This grounding system includes, through the terra-neutral (TN) grounding system in the low-voltage network and consumer installations, many, known and unknown, metallic installations typical for an urban area. As a consequence, the outgoing cable lines simultaneously become the conductive connections with the metal installations laid along the same street(s) as the feeding line. Thus it is not difficult to notice that a current flowing through the grounding system elements only as a consequence of the inductive influence of the feeding line is distributed in a very complex way between many external elements of the grounding system. It can also easily be noticed that the total current flowing through the grounding system has two, essentially different, fractions. One of them is dissipated into the surrounding earth, while the other is induced in the metal installations surrounding the feeding line. Since the process of splitting of these two fractions occurs along many external and very long grounding electrodes that are under the surface of the ground, none of these fractions can be separated and determined by direct or indirect measurements [1].

3. Determination of the actual value of series-impedance of distribution lines

The possibility of obtaining accurate values of a distribution line series-impedance is essential for both planning of a new distribution lines and operation and protection of the existing ones.