CORROSION – KEY FACTOR OF DURABILITY AND SAFETY IN THE OPERATION OF THE DISTRIBUTION POWER NETWORKS

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ABSTRACT

This paper presents the results of an in situ campaign carried on some regions of Romania in order to assess the stage of degradation by corrosion of buried components belonging to power systems. Two issues have been addressed: the first refers to the metallic armor of MV underground cables installed in a variety of soils, in locations with and without DC stray currents; the second one refers to earthing systems located in power substations. The corrosion state was visually analyzed for all studied cables in the zones of contained faults and for the metal conductors of the earthing system. For underground cables, the galvanic continuity of the metallic armors and the insulation resistance between armor and soil, respectively between armor and live conductor were also determined.

INTRODUCTION

From the sustainable development point of view, the long-life and safe operation of power equipment and installations represent a crucial problem. The service reliability of any power system depends on the proper operation of all equipment and installations belonging to the system. The power underground cables [1] and earthing networks [2] represent components of the three-phase power systems subjected to degradation by corrosion due to action of some natural (humidity, chemical and microbiological soil aggressiveness, etc.) and/or industrial (DC and AC stray currents [3], chemical soil pollution) aggressive factors.

The study and the control of degradations by corrosion of urban utilities distribution networks, especially of underground power cables, represents a complex theoretical problem, with a special practical significance. Firstly, its complexity is a result of the extension of underground metallic networks operated in the same electrolytic environment and of possible galvanic interactions among them; secondly, the multitude of factors accelerating the corrosion that act on metallic and nonmetallic materials in the soil of urban areas

For power underground cables, especially of MV and HV, the component most exposed to corrosion is the metallic armor. Its corrosion generates corrosion products with harmful consequences for the electric strength of cable insulator or, in extreme circumstances, even the ohmic interruption of the cable shield.

Traditionally, the earthing network consists of a metal conductor, or a system of metal conductors interconnected by welding, or other metallic elements acting in the same manner, embedded in the ground and electrically connected to it. In order to assure its two main functions (protective earthing and functional earthing in electric power systems), the earthing system provides interconnection or bonding to the earth of all metallic parts (exposed and extraneous conductive parts) that a person or an animal could touch – including the armor of underground cables, and the earthing of the neutral point of transformers (if necessary).

Under these circumstances, the buried metallic components of the earthing network are exposed to degradation by corrosion due to the chemical aggressiveness of the soil and especially to the existence of AC equipotential currents (originating from the protected power networks). For urban crowded areas, the action of DC stray currents issued from railways networks has to be added.

The present work has two main goals, i.e. (i) to assess the corrosion state of some buried components belonging to power distribution networks (metallic shields of MV underground power cables, and the earthing network of a HV/MV power substation, respectively) in correlation with operating conditions, and (ii) to analyze the working safety of these components.

2. EXPERIMENTAL INVESTIGATIONS

2.1. Investigations of underground power cables degradation state

The corrosive armor/soil potential – E_{cor} – of underground power cables installed in different regions of Romania (Bucharest, Cluj, Galati and Ramnicu Valcea), operated in soils with different characteristics, with and without stray currents interferences, has been assessed. In order to establish some correlations between the corrosion state of the cables and the operating environment, as well as to evaluate the electric strength of their insulation, the following parameters have been measured: the average soil resistivity on the cables path; galvanic continuity of the metallic armors; insulation resistance between armor and soil, respectively between armor and live conductor.

The experimental measurements of the soil resistivity have been performed on three points of the cable path, by the four probe method, with AC current injection in order to avoid errors produced by the DC polarization phenomena [4]; the corrosion potential armor/soil was measured to a reference electrode $Cu/CuSO_4$ [5].

2.2. Investigations of corrosion state of an earthing network

The corrosion state of the earthing network in a HV/MV substation located in Cluj-Napoca city was analyzed. The earthing network was implemented on a surface of about 10000 m^2 in 1965, and some overhauling was performed in 2001; a complete overhauling was proposed for 2005/2006. During this operation, the corrosion state of buried components was analyzed and photographically recorded and a part of earth electrodes has been replaced.

3. EXPERIMENTAL RESULTS

3.1. Degradation state of the underground cables

By analyzing the experimental results of the investigations performed on underground power lines in different regions of Romania, the following conclusions can be highlighted:

a) the copper shield/soil potentials for a series of underground cables located in Bucharest, Cluj-Napoca and Ramnicu-Valcea are more positive than the mixed corrosion potential of copper in normal soils (about + 0,1 $V_{Cu/CuSO4}$), and this fact indicates a greater risk of degradation by corrosion of these shields;

b) for the above mentioned cables, the insulation resistances between the live conductor and the shield are reduced comparatively to the normal values (2.25…50 MΩ, while the rated values for these cables are greater than 200 MΩ);

c) the copper shield/soil potentials for cables in Bucharest, Cluj and Galati vary in a large range, and this variation can be linked to the DC stray currents originating from the existing tramway railway. To all these cables (excepting those recently installed, with operating times less than 1 year), the insulation resistance between the live conductor and the shield is less than the rated value, and this fact highlights the acceleration of the physical and electric degradation of cables due to the presence of DC stray currents [3];

d) generally, greater than normal values of the shield/soil potentials for copper and steel are related to reduced values of the shield/soil insulation resistance (less than 0.5 MΩ), indicating that the corrosion state of the shields worsens after the degradation of the outer polymeric protection layer;

e) the advanced state of degradation related to underground cables can be explained by the damage of the outer polymeric protection layer during installation; this conclusion is based on the very low values of the shield/soil insulation resistances.

Figure 1 presents significant imagines regarding the degradation by corrosion and respectively the electric failure of a three-phase power underground cable.

Figure 1. Degradation and electric failure of a underground three-phase cable due to the corrosion of the metallic shield made of steel strips

The analysis of images in Figure 1 indicates that the electric failure (disruptive breakdown) of the cable occurred in a sector where the metallic shield, made of steel strips, is very corroded; this can be explained by the diminution of the insulation electric strength as a result of ionic components, their infiltration in the volume of insulator by electrochemical treeing [7] and formation of forerunner centers for the electric treeing [8].

Based on these considerations, one can emphasize that the degradation of electric strength of underground cables insulation can be put in a direct correlation with the corrosion state of cable metallic shields (armors); in its turn, the latter depends on the quality of the outer polymeric protection layer, the soil aggressiveness, and especially, on the presence of DC stray currents originating from the urban tramway railways or DC transport networks [3], [9].

3.2. Degradation of earthing network

The earthing network of the Cluj HV/MV substation was installed in 1965 and represents a complex structure (a combination of rod and meshed electrodes) aiming to guarantee low earthing resistance and favorable earth surface potential distribution. The corrosion state of different earth electrodes (vertical steel pipes and horizontal galvanized steel strips, i.e. zinc-coated) investigated during the 2005/2006 complete overhauling is presented in Figure

2. Figure 3 illustrates the armors, connected to the earthing network, of some control or signal cables installed in the same power substation.

Figure 2. Corroded elements of the earthing system installed in 1965 to Cluj HV/MV substation

Figure 3. Corroded armors of control and signal cables

All these picture show that both earth electrodes and metallic armors of underground cables are extremely corroded. For underground galvanized steel strips, the analysis of the chemical reactions determining the corrosion of Zn – Fe combination, and of related standard potentials shows that steel corrosion (of both earth electrodes and cable armors connected to earthing network) is theoretically possible only after the complete chemical stripping of the zinc coating. However, the pictures presented in Figure 3 show that metallic stripes still present, in some zones, small areas covered by zinc; this fact can be explained by the reversal of the Fe/Zn system polarity [11] in environments with oxygen that produces a faster Fe corrosion.

For the studied system, the total current through the earthing network changed between 82.4 A (measurements between 9^{00} and 12^{00} a.m.) and 69.4 A (measurements between 11^{00} and 12^{00} p.m.), i.e. a polarization current density of 1.75 – 2 A/m^2 (the total area of buried metallic structure was considered 40 m^2). Experimental results presented in [12] for OL37 steel buried in underground water show that an acceleration of corrosion process begins at about 0.3 A/m^2; higher values assessed for the studied structure can explain the advanced degradation stage of the metallic buried components.

Under these circumstances, the balance of the electrochemical system metallic structure of earthing network/soil is systematically perturbed by the AC polarization depending on the earthing current and the area of metal/soil interface. The typical polarization curve of the steel/soil electrolytic system and its response to the superposition of an AC signal clearly shows that to an AC polarization, the system responds by a distorted AC current, predominant anodic, that substantially accelerates the corrosion process accordingly to the experimental results presented in [12] and [13].

The practical determination of corrosion potential on the earth electrodes installed in 1965 have indicated values in the range + 0,02 to – 0,31$V_{Cu/CuSO4}$; the positive values have been all assessed in the south-eastern part of the substation, closed to the tramway railway (about 300 m). These differences, depending on the relative distance to the tramway railway, may suggest that, besides the AC polarization, the DC stray currents providing from the tramway network have also contributed to the corrosion of studied earthing system [14].

It is important to mention that the tramway network of Cluj-Napoca was operated since 1986, i.e. about 20 years after the installation of the studied earthing network, so we can conclude that till 1986 the corrosion rate was slower than nowadays. In order to assess the existing corrosion rate, the state of galvanized steel strips installed in 2001 during the partial overhauling was studied; values ranging between – 0.12 and – 0.34 $V_{Cu/CuSO4}$ of the corrosion potential were determined for these newly electrodes. Figure 4 shows the stage of degradation for horizontal electrodes located in the south-eastern part of the substation (zone affected by the tramway railway): the zinc coating is already quite severely corroded and this fact certifies the existence of a high corrosion rate due to the polarization phenomena produced by the simultaneous presence of AC unbalance currents and DC stray currents [3], [12 ÷14].

Figure 4. Degradation by corrosion of horizontal electrodes installed in 2001

Taking into account the above mentioned aspects and the existing technology of earthing networks we can conclude that, in nowadays conditions regarding the electromagnetic pollution of soil with AC and DC stray currents, the durability of earthing systems is quite limited. From the sustainable development point of view, in order to assure the safe operation of power systems, we consider as compulsory re-evaluation of the earthing networks design and technology, i.e. the replacement of the zinc-coated steel by other electrochemical inert materials, with a reduced rate of corrosion and electrolytic stripping [2].

4. CONCLUSIONS

Paper presents the results of an in situ campaign carried on some regions of Romania in order to assess the stage of degradation by corrosion of buried components belonging to power system, i.e. underground cables and earthing networks. The processing of experimental data collected in Bucharest, Cluj, Galati and Ramnicu Valcea allows the formulation of the following conclusions:

- cables with noticeable corroded armor present a more positive corrosive armor/soil potential, a reduced electric strength of the central insulator, i.e. a reduced insulation resistance (measured at 5 kV), and, implicitly, a higher break-through failure risk;
- except the latest installed cables (the operation life less than 1 year), all cables exposed to DC stray currents present an advanced degradation state;
- the destruction of the outer polymeric layer during cable installation can substantially accelerate the armor corrosion and electrical degradation of cables, even in soils with normal chemical aggressiveness.

Taking into account the above mentioned elements, we can affirm that the corrosion state of the metallic armor of underground cables represents the key factor for the operation security of buried electrical lines.

The visual analysis of different earth electrodes (vertical steel pipes and horizontal galvanized steel strips) investigated during the 2005/2006 complete overhauling of earthing network at Cluj HV/MV substation has indicated that all metallic components installed in 1965 exhibit an advanced corrosion state; however, a number of metallic stripes still presents, in some zones, small areas covered by zinc. This fact can be explained by the reversal of the Fe/Zn system polarity in environments with oxygen that produces a faster Fe corrosion.

The nowadays state of the earthing network can be explained by the continuous AC polarization of the interface earthing electrodes/soil over the entire operation time; this phenomenon is produced by the unbalance currents existing in power system. On the other hand, the measurement of corrosion potential has highlighted the significant contribution to this process of the DC stray currents originating from the urban tramway railways (operated in Cluj since 1986).

The analysis of the galvanized steel strips installed in 2001 during partial overhauling shows that these elements, regardless of the short operating life, are already affected by the corrosion process, and the zinc is stripped on some elements. This fact indicates that nowadays corrosion rate is very high due to the polarization phenomena produced by the simultaneous presence of AC unbalance currents and DC stray currents.

As a final conclusion, considering the necessity of continuous sustainable development in order to assure the safe operation of power systems, we consider as compulsory the re-evaluation of the earthing networks design and technology, i.e. the replacement of the zinc-coated steel by other electrochemical inert materials, with a reduced rate of corrosion and electrolytic stripping.

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