CONTRIBUTION TO STUDY OF CABLE INSULATION AGING DUE TO CHEMICAL AND ELECTRICAL STRESS

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Abstract - In a specialized laboratory setup was studied the evolution of PE dielectric insulation resistance for A2xSrY 150mm^2 and A2XS(FL)2V 150mm^2 type cable samples, following prolonged exposure to electric field action in presence of 0.1 M $CuSO_4$ solution. Experimental results suggest that aging of insulation exposed to chemical and electrical stress is due to the formation and growth (propagation) of electrochemical trees.

Keywords: power cables, insulation, aging of cables, electrochemical treeing.

1. INTRODUCTION

Durability and reliability of the power cables are determined primarily by processes of "aging" of insulation. In actual operating conditions, cable insulation is simultaneously exposed to thermal stresses, electric field, humidity and chemical aggressiveness of soil.

Under the concerted action of moisture with content of dissolved salts (ionic species) and electric field, in insulation of underground power cables are formed water and/or electrochemical trees which favors electrical trees and lead to substantial decrease of dielectric insulation [2, 3].

Development of intelligent diagnostic and preventive studies and evaluation of life time reserve for underground power cables require knowledge of the mechanism and kinetics of degradation of cables, that the behavior of the constituent materials (especially insulation) in the specific conditions of operation [4, 5].

In this context, in a specialized laboratory setup [6], was studied evolution of PE dielectric insulation resistance for A2xSrY 150mm^2 and A2XS(FL)2V 150mm^2 type cable samples, following prolonged exposure to electric field action in presence of 0.1 M $CuSO_4$ solution.

2. EXPERIMENTAL

The experimental setup is able to provide [6]:

- processing / testing cable samples length of 3÷4m exposed in an electrolyte solution to simulate operating conditions of soil;
- simultaneous testing for 3-4 cable samples;
- simultaneous measurements in different configurations / polarization;
- application, between the outer surface of the dielectric (coated with exterior semiconductor layer) and the central conductor, the voltage higher than nominal operating voltage of these cables; so for medium voltage cables (representative, U_n - 20 kV), applying of the 40kV$_{rms}$ and/or 60kV$_{cc}$ voltage;
- continuously monitoring of the voltage and currents traversing the outer semiconductor layer / solution interface;
- automatic recording of measured data with a properly configured data logger system;
- reliable and reproducible operation.

Fig. 1 and Fig. 2 show the outline of experimental installations. Representative images are presented in Fig. 3 and Fig. 4.

Samples were prepared by A2xSrY 150mm^2 type and A2XS(FL)2V 150mm^2 type cable in lengths of 3.5m. On cable samples were removed outer protective mantle and metal screens, to the level of external semiconductor polymer layer. At the ends of the cable samples, the semiconductor polymer layer was removed on 15 cm.

Cable samples were placed in test installation bath (Fig. 3 and Fig. 4), filled with solution of 0.1 M (16 g/l) $CuSO_4$ (copper sulfate), to simulate the soil conditions (humidity and salinity), especially the effect of copper ions resulted in metallic shield corrosion process.

Were performed two types of tests:

- samples exposed only to the action of $CuSO_4$ solution;
- samples exposed to the action of $CuSO_4$ solution and electric field, respectively:
  - 25kV$_{rms}$ ±10% AC voltages;
  - 35kV±10% DC voltages - anodical (+) and catodical (–) polarization, vs. inert counter-electrodes.

At the same time, for reference samples was applied an electrical stress, same for samples immersed in solution.

During measurements, the temperature for solution in bath and ambient (for reference samples) was in range 20±5°C.

Before and during testing, the insulation resistances (at 5kV) were measured with a FLUKE 1550 B teraohmeter. By data logger system, have been registered the currents by the cable samples.

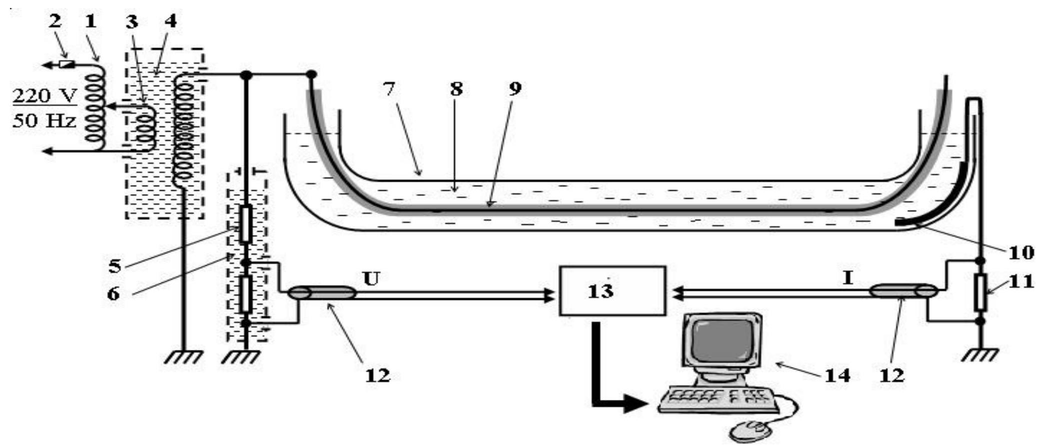

Fig. 1. Experimental setup for testing in AC polarizations:
1 - autotransformer; 2 - fuse; 3 - 220V / 45kV transformer; 4 -oil bath; 5 - voltage divider in oil bath 6; 7 - bath for AC tests; 8 - electrolyte ($CuSO_4$ solution); 9 - cable sample; 10 - counter-electrode; 11 - shunt; 12 - signal cable; 13 - data logger; 14 - PC; I – "current" signal; U – "voltage" signal.

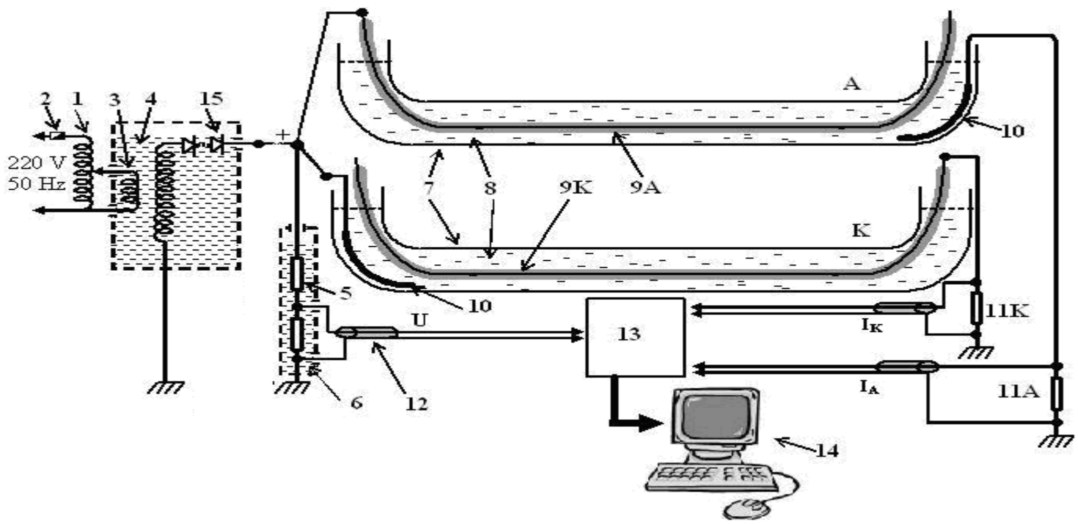

Fig. 2. Experimental setup for testing in DC polarizations:
1 - autotransformer; 2 - fuse; 3 - 220V / 45kV transformer; 4 - oil bath; 5 - voltage divider in bath oil 6; 7 - baths for DC tests (A -anodic polarization and K -cathodic polarization); 8 - electrolyte ($CuSO_4$ solution); 9A - anodical polarized cable sample; 9K-cathodical polarized cable sample; 10 - inert counter electrode; 11A - anodical current shunt; 11K - cathodical current shunt; 12 - signal cable; 13 - data logger; 14 - PC; 15 - high voltage rectifier; I_K – "cathodical current" signal; I_A – "anodical current" signal; U – "voltage" signal.

Fig. 3. Cable samples, cells and their attachments to insulating support.

Fig. 4. Control panel and data logger system.

3. RESULTS AND DISCUTIONS

Evolution of insulation resistance (measured at 5kV) for A2xSrY 150mm^2 and A2XS(FL)2V 150mm^2 type cable samples is presented in Fig. 5 and Fig. 6.

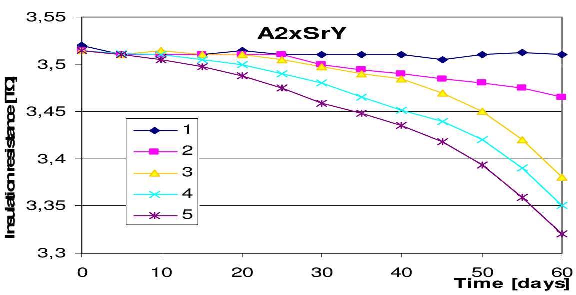

Fig. 5. Evolution of insulation resistance (at 5kV) for A2xSrY type cable samples: 1 - air stored reference sample; 2 - immersed reference sample; 3 - AC polarized (25kV$_{rms}$) sample; 4 - anodical polarized (+35kV) sample; 5 - catodical polarized (–35kV) sample.

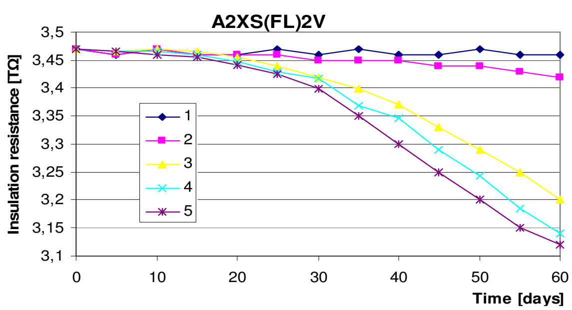

Fig. 6. Evolution of insulation resistance (at 5kV) for A2XS(FL)2V type cable samples: 1 - air stored reference sample; 2 - immersed reference sample; 3 - AC polarized (25kV$_{rms}$) sample; 4 - anodical polarized (+35kV) sample; 5 - catodical polarized (–35kV) sample.

Fig. 5 and Fig. 6 shows that during the investigation (60 days), the insulation resistance of air stored reference cables samples (curves 1) do not change after polarization at 25kV$_{rms}$. For immersed in $CuSO_4$ solution samples without polarization (curves 2), after initiation of approx. 25 days of immersion, there is a clear decreasing trend of insulation resistance, and after 60 days of treatment it reaches approx. 99% of baseline. It also shows that for the sample polarized in AC with 25kV$_{rms}$ (curves 3), insulation resistance does not change at first, but after about 25 days of treatment begins its decrease, reaching about 96% of baseline (after 60 days of treatment). Greater decreases of insulation resistance were registered in case of DC polarized samples, especially catodical polarized (curve 5), which, after 60 days of treatment, reaching approx. 94% of baseline.

In case of immersed sample without applied voltage, the behavior can be explained by absorbing (on the surface of semiconductor layer) of ionic species presents in solution (Cu^{2+}, respectively SO_4^{2-}) followed by their diffusion in the dielectric volume. Evolution of insulation resistance for AC polarized immersed sample can be explained by formation (in the presence of solution and applied voltage) of water trees and electrochemical trees. Formation of water trees begins [7] after a initiation period t_i which depends on the applied signal frequency f (in our case, 50Hz), intensity of applied electric field E and a constant A that depends on the dielectric material, respectively (1):

$$t_i = A \cdot f^{-1} \cdot E^{-3,5} \qquad (1)$$

Once started, the water trees rapidly increase. There are many relations for tree lengths variation in time, the known is the relation of "power" [7], in good agreement with the shape of the curve 3 in Fig. 5.

According to (1), at polarization in DC, trees should not initiate because t_i becomes infinite for f = 0. The experimental results refute this (curves 4 and 5 of Fig. 5 and Fig. 6). In fact, there are a faster initiation and higher growth rates for polarization in DC (both anodic and cathodic) than the polarization in AC. These results are explained by the fact that in the experimental setup (Fig. 2), the samples are polarized with a half-wave rectified AC pulse (voltage pulse); in this conditions, according to [7], are favored initiation and growth of water trees (experimentally confirmed by curves 4 and 5 of Fig. 5 and Fig. 6).

In Fig. 7 is presented the comparative evolution of insulation resistance of investigated cables, during their stressing at 25kV$_{rms}$ ± 10% in 0.1 M $CuSO_4$ solution.

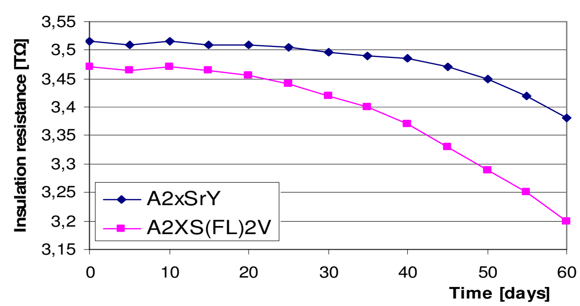

Fig. 7. Comparative evolution of insulation resistance (at 5kV) during AC polarization at 25kV$_{rms}$ ± 10%.

In Fig. 7 is observed that the polarization in AC, initiation period t_i is about 10 days greater for A2xSrY than A2XS(FL)2V, in the given experimental conditions. It also shows that insulation resistance measured for A2xSrY is systematically higher than A2XS(FL)2V, suggesting that the trees growth rate is higher for A2XS(FL)2V than A2xSrY. Similar developments occurred both anodical pulse polarization (+35kV±10%) and cathodical pulse polarization (-35kV±10%) of the investigated conductors (Fig. 8 and Fig. 9).

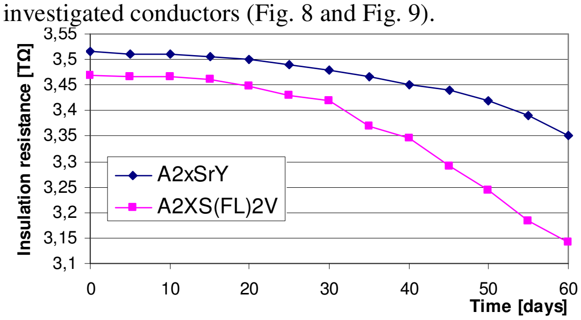

Fig. 8. Comparative evolution of insulation resistance (at 5kV) during anodical polarization at +35kV.

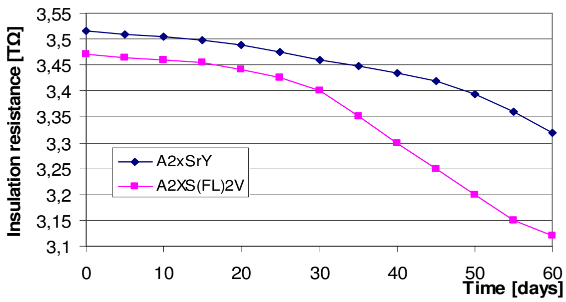

Fig. 9. Comparative evolution of insulation resistance (at 5kV) during cathodical polarization at –35kV.

Comparative evolution of currents, through investigated samples, is in good correlation with measured values for insulation resistance (Fig. 10, Fig. 11 and Fig. 12).

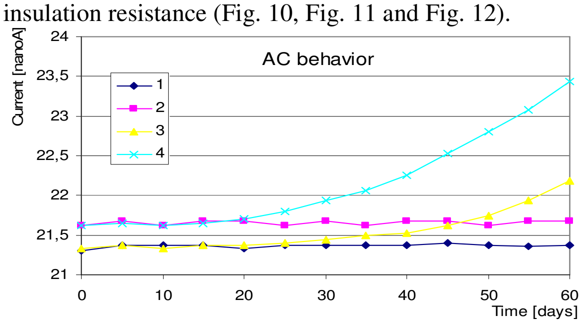

Fig. 10. Comparative evolution of currents during AC polarization at 25kV$_{rms}$: 1 - A2xSrY air reference sample; 2 - A2XS(FL)2V air reference sample; 3 - A2xSrY in solution 0,1 M $CuSO_4$; 4 - A2XS(FL)2V in solution 0,1 M $CuSO_4$.

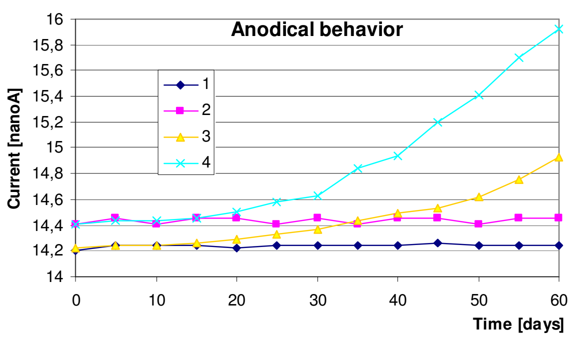

Fig. 11. Comparative evolution of currents during anodical polarization (+35kV): 1 - A2xSrY air reference sample; 2 - A2XS(FL)2V air reference sample; 3 - A2xSrY in solution 0,1 M $CuSO_4$; 4 - A2XS(FL)2V in solution 0,1 M $CuSO_4$.

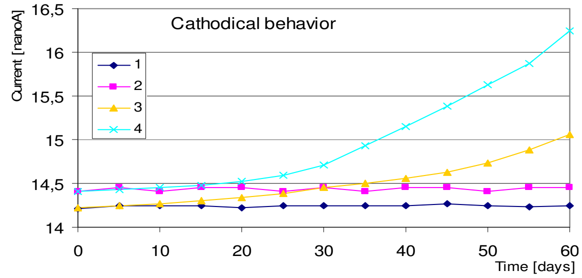

Fig. 12. Comparative evolution of currents during cathodical polarization (-35kV): 1 - A2xSrY air reference sample; 2 - A2XS(FL)2V air reference sample; 3 - A2xSrY in solution 0,1 M $CuSO_4$; 4 - A2XS(FL)2V in solution 0,1 M $CuSO_4$.

As Fig. 10, Fig. 11 and Fig. 12 shows, at both AC polarization and DC pulse polarization (anodical and cathodical) on the samples in air, currents through the cables have relatively constant value (curves 1 and 2) during the test (60 days). For samples immersed in 0.1 M $CuSO_4$ solution, in correlations with trees formation and growth, the currents increase (curves 3 and 4), the largest increases being recorded for A2XS(FL)2V polarized cable (curve 4).

Also, in Fig. 11 and Fig. 12, notes that, the currents through the investigated cable samples are higher for negative polarization pulse. This is because, at the cathodic polarization of the conductor of cable sample, on the surface of external semiconducting layer focusing copper ions (Cu^{2+}), which penetrates the dielectric volume through opened water trees. In case of anodic polarization, similarly, but penetrates sulfate ion (SO_4^{2-}). Diameter of Cu^{2+} is much smaller than that of SO_4^{2-}, so copper ions penetrates much deeper into the insulation than sulfate ions, with corresponding loss of insulation resistance and increase of currents through dielectric.

4. CONCLUSIONS

From the experimental data result:

- under applied electric field on the air stored samples, their insulation resistance and currents through dielectric were not significantly changed during the investigation (60 days) - deviations were recorded up to 0.5%;
- after immersion in solution of cable samples, without electric field application, about 35 days of immersion, the insulation resistance is reduced, so that at 60 days of immersion were decreased by approx. 1% for both types of investigated cables;
- under action of 50Hz AC field, after a initiation period, insulation resistance of cable decreases as follows:
  - for A2xSrY - about 25 days initiation period, insulation resistance after 60 days decreased by approx. 4% of initial value;
  - for A2XS(FL)2V - about 18 days initiation period, insulation resistance after 60 days decreased of 7.3% of initial value;
- under action of positive pulses with the peak of 35kV, the periods of initiation are greatly reduced and

insulation resistance decreases are more pronounced than in case of AC polarization, namely:
  - for A2xSrY - about 10 days initiation period, insulation resistance after 60 days decreased of approx. 6% of initial value;
  - for A2XS(FL)2V - about 15 days initiation period, insulation resistance after 60 days decreased of 9.7% of initial value;
- under action of negative pulses with the peak value of 35kV, initiation periods are reduced much more and insulation resistance decreases are more pronounced than in case of anodic polarization, respectively:
  - for A2xSrY - about 7 days initiation period, insulation resistance after 60 days decreased of approx. 7% of initial value;
  - for A2XS(FL)2V - about 10 days initiation period, insulation resistance after 60 days decreased of 10% of initial value;
- during polarization of investigated cables, currents through dielectric are in good agreement with the trend of insulation resistance (measured at 5 kV).

The insulation resistance decreases and the currents through cable dielectric increases are the facts that the electrochemical trees initiate and then grow, during the polarization of cables immersed in electrolyte.

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