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AGEING EFFECTS OF POLYETHYLENE INSULATION OF POWER MEDIUM VOLTAGE CABLES EXPOSED TO ACTION OF MOISTURE

1. Introduction

The formation of the mechanism of water treeing and its effecting on the reliability of polyethylene (PE) insulated power cables are not sufficiently recognized in the technical literature in spite of extensive research work which has been carried out. At least three basic hypothesis of the water treeing in PE are discussed [4]. Actual opinions of the problem of danger for the PE insulation through contact with water are different, too. The real danger of a breakdown of the insulation by elongation of the water tree is most frequently pointed out. The test techniques of the PE resistance to water treeing are made [2]. It is accepted that the initiation of the water trees requires two things. The first one is the presence of a conducting liquid or a water vapour in contact with PE [3] and the second one is an electric field with an intensity far less than necessary for growing of electrical trees.

It is expected that the water treeing causes changes in the properties of the PE insulation during a time, for instance loss factor, resistivity or electric strength. The results of the first research stage are described in this paper. It investigates this problem on PE insulated medium voltage cables.

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2. Test methods

Investigations were carried out on cable samples with thermoplastic polyethylene insulation of 15 kV rate. The cable had an aluminium conductor twisted from several wires with a total section of 120 mm^2 which was covered by an extruded type shield. The concentric conductor of that cable consisted of several copper wires wound on the tape type insulation shield.

Tests were performed on 4,75 m samples ended by special laboratory terminations which were partial discharge-free in the range of the used testing voltages. Cable samples were taken from one manufacturing cable segment in which the discharge inception voltage was equal 14 kV at 5 pC sensitivity.

As the basic criterion in evaluating the influence of moisture on the dielectric properties of the PE insulation the time to the breakdown of the cable sample insulation in a voltage endurance test has been taken. During that test the alternating voltage of a constant value, moisture and cyclic changes of the insulation temperature acted simultaneously. Such conditions simulated the dangers which may act upon the cable insulation in service. The cable samples were divided into three groups of 6 segments:

group A - dry samples ([illegible] group),

group B - samples with water at the conductor,

group C - samples with water at the concentric conductor.

The cable samples have been weted by a solution of destilled water with 0,1% ammonium chloride (NH_4Cl). That solution filled the voids in the core or concentric conductor. Solution decrements were systematically refilled with new electrolyte during the test.

The cable samples were subjected to action of an alternating voltage of 4 U_0 = 34,[illegible] kV and cyclic changes of the insulation temperature from 20°C (ambient temperature) up to 70°C with six hour cycles of [illegible] and cooling. The measurements of the loss factor and the [illegible] were carried out periodically during the endurance test. After the [illegible] the impulse strength investigation were carried out and the [illegible] insulation specimens were examined microscopically.

3. Life to the breakdown

The cable samples with water in the conductors (group B) had the least life to the breakdown under test conditions, whereas the highest one had the samples with water in the concentric conductor (group C) which did not break down in spite of the fact that the test was performed up to 2 000 hours. The parameters of the time distribution to breakdown of the investigated cable samples are shown in Table 1. A Weibull distribution has been used.

Table 1

Parameters of time to breakdown distribution of PE insulated cable samples rated 15 kV in voltage endurance test of 34,6 kV

Cable group	Scale parameter h	Shape parameter	State of insulation after testing
A	1,038	1,82	Strong erossion of PE surface
B	989	3,44	Strong erossion of PE surface, numerous water trees of bow-tie type
C	2,000	-	No breakdown of insulation, numerous water trees of bow-tie and delta types

Egzaminations of the cable insulation sample stated after the voltage endurance tests have shown that the breakdowns of the cable insulation at group A and B have been caused by a strong erossion of the outer insulation surface as result of the partial discharge action in the gaps of the concentric conductor. The discharge inception voltage measured periodically in the cable samples of groups A and B decreased from 14 kV to 6 kV with a simultaneous increase of the discharge magnitude from 40 pC to about 400 pC at the test voltage equal 21,6 kV.

The action of such partial discharges on the PE surface causes formation of craters of a long shape gaseous cavity which are changed into breakdown canals at the continued action of testing voltage [5]. All breakdown canals were situated in the areas of the strong surface erossion.

The presence of water in the conductor of cable samples (group B)has caused the generation inside the insulation of numerous water trees of bow-tie type (see Table 2) which were absent in the insulation of group A samples. One can say that the presence of water trees in the insulation does not effect principally the decrease of the time to breakdown in the voltage endurance test of PE insulation - the acting of partial discharges has a greater importance.

Table 2

Parametres of water trees in PE insulated cable samples rated 15 kV exposed to action of moisture

Cable group	Water trees of bow-tie type			Water trees of delta type		
	a mm	b mm	n $1/mm^3$	a mm	b mm	n $1/mm^2$
B	0,07	0,3	300	-	-	-
C	0,05	0,1	170	0,01	0,01	30

a - average length, b - maximal observed length,
n - maximal observed quantity

The test results on cable samples of group C in which the water filled the voids in the concentric conductor confirm the above conclusion. In these samples partial discharges did not develop, thus there was no outer surface erossion of the PE insulation. None of the investigated samples did break down in spite of the endurance test of 2,000 hours and the emergence inside the insulation numerous water trees of the bow-tie and delta types. The trees of the second pattern were situated at insulation shield.

The fact that there were no principal differences between the distributions of the time to breakdown at the cable samples of groups A and B was also confirmed by the statistical tests. All these times comprise one distribution with the Weibull parameters T_0 = 998 hours and m = 2,9.

4. Loss factor

The loss factor of the cable insulation has been measured at less test voltage than the discharge inception voltage of cable sample (usually U_0) in order to omit the losses which are connected with partial discharges. The measurement results are strongly dispersed, the variation coefficient usually equals from 45% up to 60%. This fact makes the result of analysis difficult and does not allow conclusions.

In spite of these weak points the dependence between the PE insulation loss factor of the cable samples and the way of their watering may be seen (Fig.1).

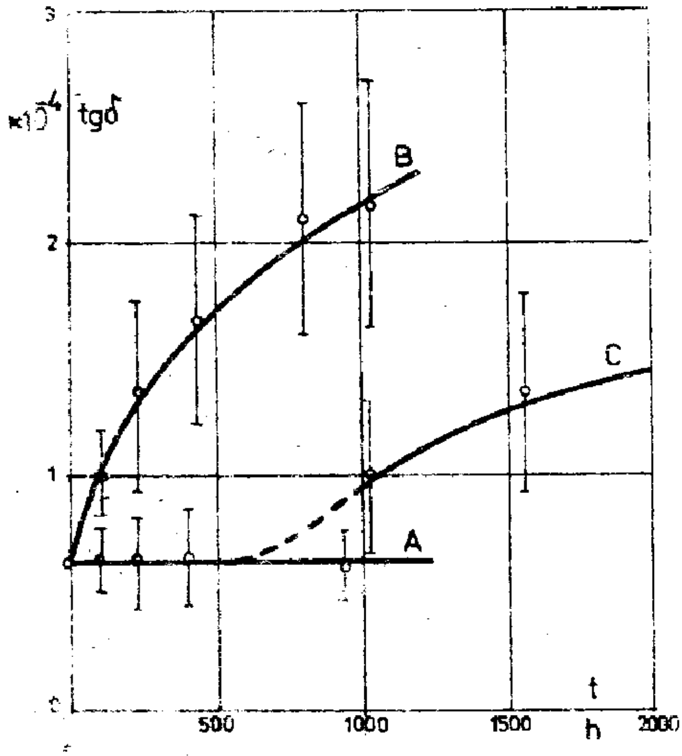

Fig.1. Variation of loss factor of the PE insulation with time of the voltage endurance test

The loss tangent of the group A cable samples did not change practically during the voltage endurance test. In the cable samples of group B a steady increase of the loss factor was observed. It reached a value about

3 times greater than tan δ of the unaged PE insulation after 1,000 hours of the test. In the group C cable samples the loss factor did not change during the first 1,000 hours of testing. After that it increased similar as the loss factor of the group B samples reaching after the next 1,000 hours a value which was about 2 times greater than tan δ of the unaged cable.

Concerning cable samples of group B it may be stated that the loss factor had decreased in the period without a voltage after the endurance test (Fig.2).

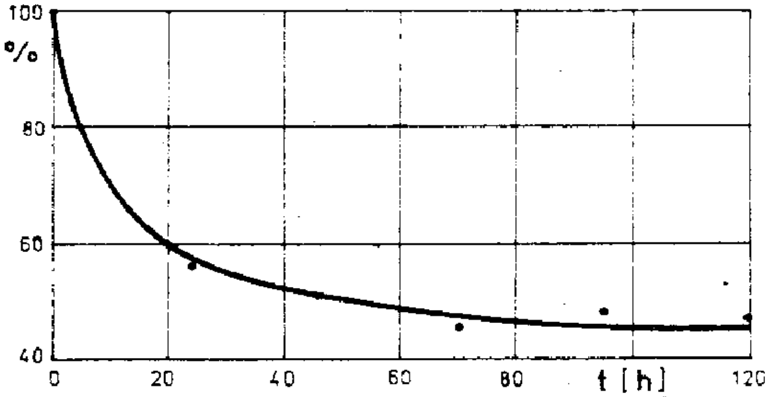

Fig.2. Variation of loss factor of the PE insulation with time after switching the test voltage off

If the tan δ value which a sample has after particular period of the endurance test is assumed as 1 then after switching the test voltage off there will be the fast decreasing of the loss factor. The state value equals about 0,5 and the principal changes occur in a time to 20 hours from the moment of switching the test voltage off. This phenomenon may partially explain a great dispersion of the loss factor values in the tested cables. This may also in a principal way influence the changes of the PE loss factor in the voltage endurance test during which the unvoltage breaks are inevitable (insulation breakdown, control measurements and others).

The obtained measurement results show the action of moisture on the PE insulation in according to the following scheme:

a) electrolite parts penetrate into voids between the PE chains, the electric field having a direction conformable to the diffusion direction greatly accelerates and amplifies that process,

b) after switching the test voltage off, a reverse process starts:drying of PE insulation, though a part of the electrolite still remains inside the insulation.

Similar conclusions have been formulated in paper [3] based on model investigations.

5. Volume resistivity

The PE insulation volume resistivity of the cable samples has been measured at a direct positive voltage of 50 kV terminated to the conductor.

It has been stated that the volume resistivity of the PE insulation in all cable sample groups decreases with the voltage endurance test time. That variation clearly depends on ageing factors to which the insulation was subjected, as shown in fig. 3.

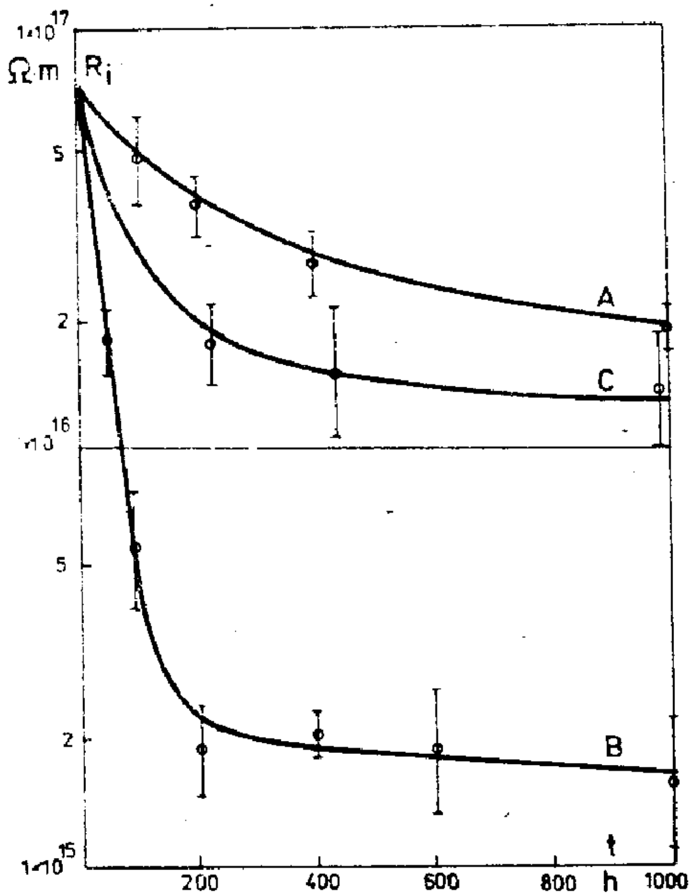

Fig.3. Variation of volume resistivity of the PE insulation with time of the voltage endurance test

The biggest variations occured in the samples of group B in which already after 200 hour test the volume resistivity decreases about 50 times in comparison with the initial value.

It may be seen that the volume resistivity variations are caused by effects occuring inside the insulation. The presence of water inside the insulation increases in a decisive manner participation of the ion mechanism in electric conduction. Water penetration into the PE insulation is easier when its direction is in accordance with the electric field direction and the temperature gradient. These facts are the easy explanation of the differences between the curves R_1 = [illegible] shown in Fig.3 for the cable samples of groups B and C. Partial discharges acting in the tape insulation shield are another factor influencing the decrease of the PE volume resistivity. These discharges cause the structure changes in the PE insulation leading to an increase of the electron conduction [[illegible]]. The results of the action of that factor are far less (curve A in Fig.3) than the action of water.

The resistivity measurements are able effectively to detect wetting of the PE insulation of power cables.

5. Impulse strength

Impulse strength investigations were carried out in order to determine the influence of moisture on the short-time strength of the PE insulation. In comparison with short-time investigations at the alternating voltage they provide a couple of advantages. For instance, using both polarities of impulses applied to the cable sample core, the insulation defects situated close to the conductor (positive impulses) or to the screen [illegible] conductor (negative impulses) can be detected [[illegible]].

As a measure of short-time strength the number of impulses to the breakdown of the PE insulation has been taken. The impulses of both polarities had the shape of 1.2/50 and the constant peak value [illegible]. The investigations were carried out at an insulation temperature [illegible] ambient temperature (20°C). The cable samples were examined after [illegible] of the [illegible] places formed during the voltage [illegible] the samples had various ageing times [illegible] ned results can serve only a qualitative evaluation of the investigated phenomenon.

The cable samples aged during about 1,000 hours without moisture (group A) withstood 20,000 positive impulses. In the same samples a breakdown at negative impulses occures already on the level of 17,000 impulses. That decrease of impulse strength is caused by distinct erossion of the outer insulation surface.

The impulse strength of samples exposed to action of moisture is far less and a direction of water diffusion to the PE insulation has a great influence on that decrease. In group B where water penetrated in accordance with field direction, the number of impulses to the breakdown decreased to the level of several hundred positive impulses (an average 370 impulses in 4 investigated samples) after about 1,000 hours of ageing.

In the samples of group C where the directions of the electric field and the water diffusion were opposite, the decrease of the impulse strength was less in spite of twice as long time of ageing and it occured only at a negative polarity. The number of impulses to the breakdown reached a level of several thousands of the negative impulses (an average 3700 impulses in 3 investigated samples).

Results of the impulse strength investigation show that moisture at the PE insulation causes a considerable decrease of short-time electric strength. The penetration of water from the side of the conductor is more dangerous for cable reliability. In practice this can cause a considerable increase of the number of defects in the PE cable insulation subjected to the action of moisture and situated in places where a great number of lightnings occures.

7. Conclusions

The investigations that were carried out are able to formulate several conclusions concerning the influence of moisture upon the electrical properties of the PE cable insulation:

- action of moisture on the PE insulation under conditions of voltage endurance test leads to the development of water trees of bow-tie and delta types,

- presence of moisture in the PE insulation does not influence the time to breakdown under used conditions of voltage endurance test, whereas it causes a great decrease of the short-time strength.

- conductivity and loss factor of the wetted PE insulation are greater than in the dry insulation, the resistivity measurements can be a good indicator of the quality of PE insulation in service,

- contact with water comprises a real danger for the PE insulation stability and the case of water action upon the cable insulation according to the direction of the electric field is even more dangerous.

References

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