Stanisław Wojtas, Henryk Boryń, Eugeniusz Wasilenko, Andrzej Wiśniewski

DEGRADATION OF EXTRUDED CABLE INSULATION IN ONE AND THREE PHASE TESTS

1. Introduction

Three-phase extruded insulation cables for rated voltage up to 6 kV may be produced without semiconducting shields on the conductors and on the core insulation. The Polish standard [1] allows manufacturers to make such cables using only polyvinyl chloride (PVC) which is the material more resistant to the action of partial discharge erosion than polyethylene (PE). The standards of other countries accept in such cable construction also PE insulation. For instance standard [2] permits producers to use that material up to the voltage of 3 kV and another standard [3] even up to 6 kV.

Three-core cables without conducting shields are characterized by the simple structure and easier manufacturing process. But some problems arise when a research program is established to evaluate the technical properties of the investigated cable construction. The standards mentioned above provide that endurance tests of the cables ought to be carried out with the 1-phase voltage system instead of the 3-phase one. In the case of a radial field cable this has no meaning importance. In a cable with a core binder the 3-phase voltage field distribution differs significantly from the 1-phase voltage distribution i.e. the electric field tangent components acting on the insulation surface appear and this can intensify a degradation process of the cable insulation.

The main purpose of this work is a comparison of the endurance test results at the 1-phase voltage with the 3-phase ones. The investigations were performed with cables without both conductor shields and insulation shields.

Dr. Stanisław Wojtas, Dr. Henryk Boryń, Ass. Prof. Dr. Eugeniusz Wasilenko, Eng. Andrzej Wiśniewski - The High Voltage and Electrical Apparatus Institute of the Gdańsk, Technical University

2. Research programme

Investigations were carried out on a three core cable model with a PE insulation without both conductor shields and core shields. Its section is shown in Fig. 1. An aluminium conductor of 240 mm^2 section consists of a sector shape conductor of 120 mm^2 braided by 16 wires of 3 mm diameter.

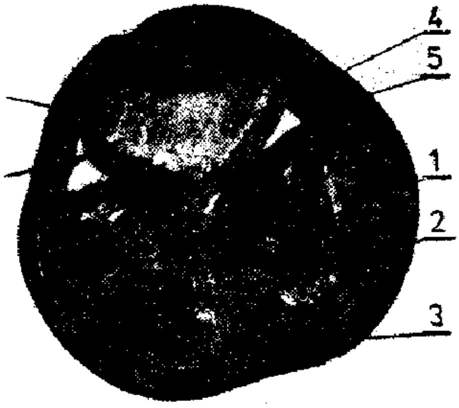

Fig.1. Section of cable model
1-working conductor, 2-PE insulation, 3-estrofol and PVC tapes, 4-return conductor, 5-PVC jacket

The insulation of minimal thickness of 3,3 mm is made of milky - white colour polyethylene with the irganox 1010 stabilizator. The cable core binder consists in turn of one estrofol tape and one PVC tape 0,3 mm in thickness. The return conductor composed of two copper tapes of a total section of 18 mm^2 is coated with a PVC jacket of thickness of about 2 mm.

The endurance voltage tests were carried out on cable samples of the measure length of 2,6 m. The times to the breakdown of the individual core insulation at the 3-phase system voltage of 20/34,6 kV and at 1-phase system voltage of 20 kV were compared. The 3-phase field distribution in the cable lasted to a breakdown of the first core. After the breakdown the core has been disconnected and left unearthed i.e. the system has been transformed into a 2-phase one and next as a result of a sequent breakdown into a 1-phase system. One-phase voltage system investigations were performed in two versions namely

a/ the voltage has been applied between the tested cable core and the earthed return core while the other cores were earthed,

b/ the voltage has been applied between the tested core and the earthed return core while the other cores were unearthed.

Partial discharges are consider to be the most dangerous for this type of cables in endurance voltage test and thus their ignition voltage at a sensitivity of 5pC has been measured. It has been tried to lokalise these discharges and to explain the mechanism of their effect upon the cable insulation.

3. Investigation results

The obtained times to breakdown in 3-phase voltage test and at both 1-phase voltage tests are shown in Table 1.

In each system were tested 5 cable samples carried out by using the Weibull distribution. The scale parameters To and the shape coefficient have been counted. Two results (0,4 h and 0,9 h) situated clearly out of the distributions and probably due to technological defects of the insulation were neglected. Fig 2 shows the time distributions to the first breakdown in the systems: a - in the 3-phase system, b - in the 1-phase system with the earthed two remaining conductors, c - in the 1-phase one with the unearthed remaining conductors. By a comparison of the scale parameters of the distributions a, b and c one can see that the test conditions of the 3 phase voltage system seem to be the most dangerous for the cables (T_0 = 76,5 h), next the test conditions of the 1-phase system with earthed remaining conductors (T_0 = 197 h) and the soft test are the test conditions with unearthed remaining conductors (T_0 = 339 h). The shape coefficient of the distributions are contained within the limits of 1 to 2.

The test conditions of the 3-phase voltage system are going through changes as the cable cores are sequently subjected to the cable brakdown.

Table 1

Times to a breakdown of the tested cables at the 3-phase voltage of 20/34,6 kV and at two test versions of the 1-phase voltage of 20 kV

Sample No	Test	Times to breakdown [h]			T_0 [h]		
		1-st	2-nd	3-th	1-st	3-th	all
1	3-phase	56,8	143	205			
2		53,0	66	300			
3		113,0	643	>1000	76,5	647	-
4		32,0	98	907			
5		0,4	103	174			
6	1-phase, earthed	109,0	250	376			
7		189,0	254	412			
8		395,0	514	537	197	-	343
9		35,0	81	162			
10		99,0	299	763			
11	1-phase unearthed	168,0	860	>1000			
12		0,9	145	160			
13		393,0	709	>1000	339	-	720
14		291,0	365	>1000			
15		171,0	535	910			

Fig 3 shows the time distribution to the 3-th breakdowns in the 3-phases system - line a and also the times to all breakdowns in both 1-phase voltage tests: with earthed remaining conductors - line b and with unearthed remaining conductors - line c. The scale parameters T_0 are 647 h (a), 343 h (b) and 720 h (c) respectively. The distributions a and c have similar scale parameters because the 3-phases test transforms into the 1-phase one with unearthed remaining conductors when two cores in each cable sample are broken down. A less cable strenght in the 3-phase test is due to a certain degradation of the core insulation at the time to breakdowns of the two forgoing cores.

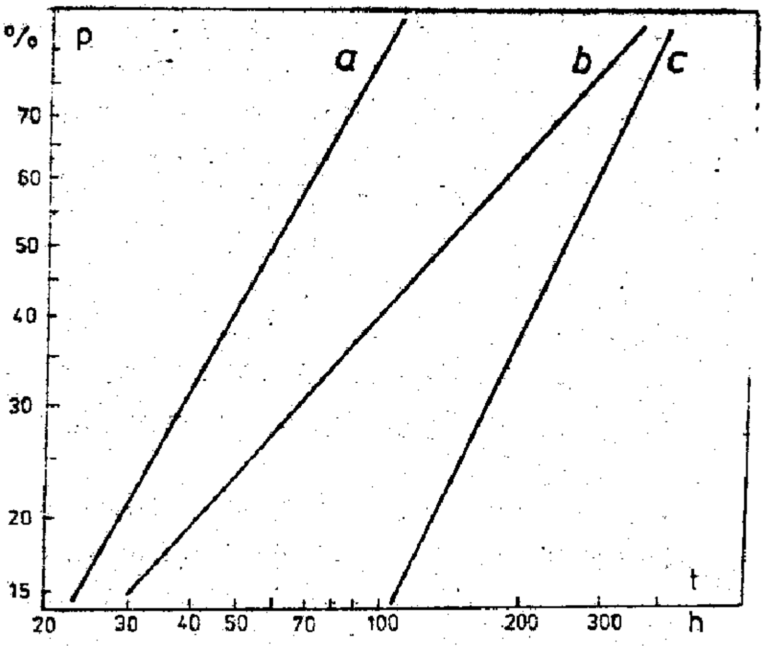

Fig.2.Time distributions to first breakdown
a- 3-phase test, b- 1-phase test with earthing, c- 1-phase test without earthing

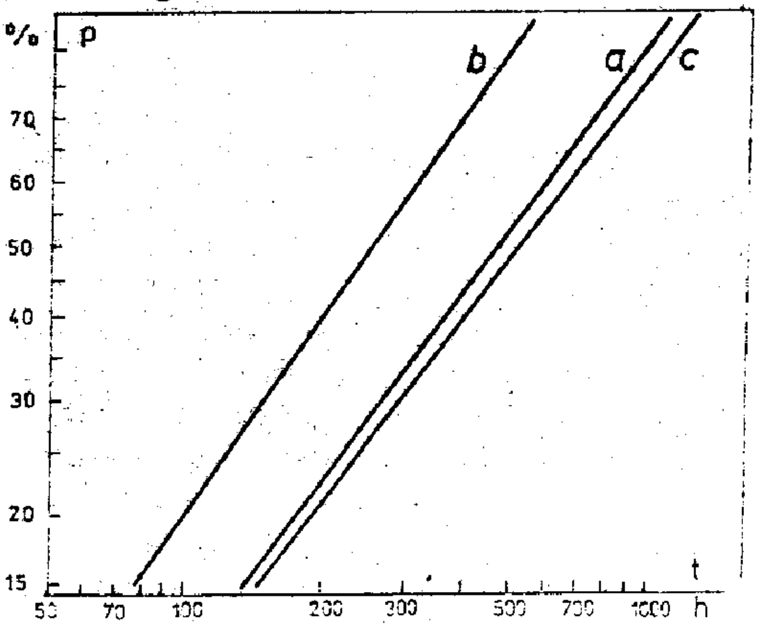

Fig.3. Time distributions to 3-th brakdown in 3-phase test - line a and to all breakdowns in 1-phase test with earthing - line b and without earthing - line c.

All breakdowns obtained in the described investigations reached the earthed return conductor and the majority of them occurred in the border zone of the neighbouring cores. The places have been signed in Fig.1 by arrows. While the 3-phase voltage is applied to the cable cores the electric field intensity in this zone increases in comparison with the intensity caused by the 1-phase voltage. During the 1-phase test with unearthed remaining cores there is induced on these cores a voltage of about 15% of the supply voltage due to capacitive coupling. Thus the effective voltage between the neighbouring conductors is equal only about 85% of the full test voltage and this brings about to a softening of the test conditions.

Earlier investigations showed that the errosive action of partial discharges on the PE insulation has a considerable influence on the endurance test results [4]. The existing measurement systems of partial discharges are accomodated to 1-phase system tests. So, there is no possibility to measure these discharges which are connected with the presence of the 3-phase voltage. Measurements of partial discharges have been carried out in following system in which a 1-phase probe voltage has been applied between:

a/ connected with themselves cable cores and the earthed return conductor,

b/ the single cable core and the earthed return conductor as well as the two remaining cores,

c/ the single cable core and the earthed return conductor with unearthed remaining cable cores.

The ignition voltage of the partial discharges of the amplitude of 5pC has been measured with the following values for the systems: a - 4,0 kV, b - 4,5 kV, c - 5,9 kV. The system c with two unearthed cable cores has the least partial discharges intensivity. The cause is probably of the same kind as in the endurance test, namely the decrease of the voltage between the feed cable core and the unearthed cores.

One has also tried to localise discharge sources. Pouring electrolythe into the voids between the insulation of the cable cores reduces the maximum charge of recorded discharges with no effect on their ignition voltage. The ignition voltage at the sensitivity of 5 pC in the tested cable model increases up to about 11 kV only after pouring the electrolythe into the working conductors.

As a result of these tests it has been stated that partial discharges developing in the air gaps between the conductor and the insulation are decisive for the value of the discharge ignition voltage in such cables. The partial discharges in the outer spaces of the core insulation develop at higher probe voltages and increase clearly the maximum charge value of the recorded discharges in a tested cable sample.

Examinations of the discharge places and the state of the insulation after the test confirmed the partial discharge presence on both sides of the core insulation as well as their destructive effect upon the insulation. The inner discharges between the working conductor and the insulation seem to have been a direct cause of the cable breakdowns. These discharges cause an errosion of the PE insulation and this lead to a crater formation on the inner surface of the insulation. During the microscope examination craters with a depth of about 0,4 mm have been found. In Fig 4 it can be seen that a breakdown canal developed from the working conductor in the return conductor direction. This suggestion confirms the mentioned above direct cause of the breakdowns.

The partial discharges developing in the voids between the core insulations cause fogging of the insulation surface and a change of the insulation colour. After a few hundreds of hours of probe voltage action a change of the PE colour from milky - white into yellow in the places of the most intensive partial discharges has been stated. The change of the insulation colour became deeper and deeper and after a next few hundreds hours reached the whole insulation thickness i.e. about 3 mm.

Fig 4. Breakdown canal section

Furthermore, a degradation of the estrofol tape which surrounded the cable cores has been noticed - Fig.5. The biggest destruction was observed on the borders of the cores i.e. in places where the partial discharges are the most intensive.

Fig.5. Degradation of estrofol tape after endurance voltage test

4. Conclusions

4.1. For 3-phase cables without shields on both conductors and core insulations endurance voltage tests ought to be performed in the 3-phase system (the time to the first breakdown taking under consideration). Feeding the cable by 1-phase voltage makes the test conditions softer.

4.2. The times to the breakdown in the endurance test of the examined cable model with the PE insulation were limited by the erosive mechanism under the influence of the partial discharges.

4.3. The ignition voltage of partial discharges in cables without both conductor shields and insulation shields results from the presence of air gaps between the working conductor and the insulation.

4.4. In the case of a designing of a PE cable without core shields air gaps between the working conductor and the core insulation ought to be eliminated.

5. References

1. PN-76/E-90300 - Kable elektroenergetyczne i sygnalizacyjne o izolacji z tworzyw sztucznych na napięcia znamionowe nie przekraczające 18/30 kV.

2. IEC Publ. 502.1-1975 - Extruded solid dielectric insulated power cables for rated voltages from 1 kV up to 30 kV.

3. NKF H 75-35 - Netherlands specifications for PE or XLPE insulated high voltage cable and accessories.

4. Wasilenko E. - Przebicie długotrwałe izolacji polietylenowej przy napięciu przemiennym 50 Hz, Zeszyty Naukowe Politechniki Gdańskiej, Elektryka XLV, 1978 r.