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Problems of Automatic Test of Insulation in Cable Production

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Abstract. The article presents a qualitative and quantitative assessment of cable products insulation defects that can be reliably detected by means of the electrosparking control during the cable production process. The performance potential of technological control is evaluated: the limit of reliable detection of defective places in insulation taking into account the technical capabilities of modern control devices is marked.

1. Introduction

Electrosparking control of cable products insulation is regulated by a number of national and international standards [1–5] and it has been widely used in the cable industry since the 50s of the 20th century. Despite of the great world experience of its application, there are a number of unresolved issues, one of which is the lack of a unified approach to the qualitative and quantitative assessment of detected defects [6–8]. Experts in this field have different opinions about the control possibilities. There is a widespread belief that the electrosparking defect detector may detect furthermore the micro-defects in the insulation layer. Moreover, currently a large number of control devices of various types and manufacturers is applied and their defect detectors are based on different principles of operation [9, 10]. This often leads to the control reliability decreasing and production costs increasing. This article presents the results of theoretical and experimental studies aimed at addressing this issue.

2. Theory

In order to analyze the defect detection possibility it is proposed to classify the factors of the electric field and the insulation defective area interaction on the three basic physical signs [11–13].

The first and basic sign: a defect presence leads to a reduction of the insulation area dielectric strength, which in turn will leads to an electrical breakdown during the electrosparking control.

The second sign: an insulation defect consists in the geometry or the material properties changing. Both of them inevitably lead to a change in capacitance and dielectric losses in the defective area. Consequently, defects can be revealed by controlling the capacitance and / or dielectric losses of cable products insulation.

The third sign is the level of partial discharge in the insulation defects under its internal layers. The partial discharge high level indicates the presence of porosity, air pockets in insulation; violation of the solidity and homogeneity.

In this paper the defect detecting possibility upon an electrical breakdown is studied on the example of the main cable insulation materials such as PVC plasticate, polyethylene and rubber.

The main types of manufacturing defects in the cable products insulation are shown in the figure 1.

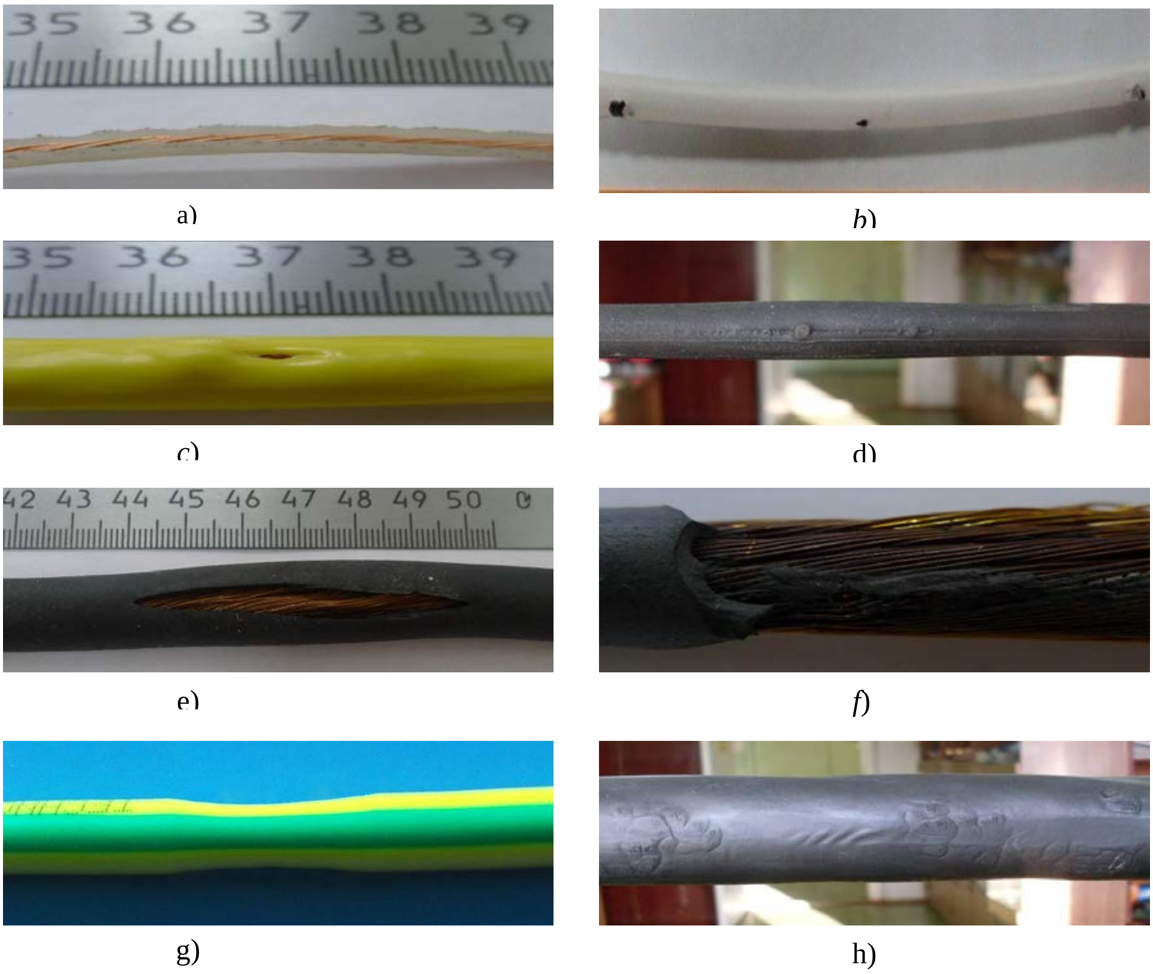

Figure 1. The main types of cable products insulation defects, insulation "slice" – a; impurity inclusion – *b*; local rupture of insulation and bumps – *c, d, e*; insulation material adhering on the cable cores – *f*, insulation porosity – *g*; outer diameter inequality, buildup along the insulation surface – *h*.

The physical principle discussed control type lets to detect only those types of defects, in which a spark discharge takes place in a short time finding the cable insulation area in the control zone (about 0.001..0.1 sec). It is shown by a long-term practice that when voltage levels selected for different thicknesses of insulation made of rubber or plasticate, in accordance with the test assessment references, the spark discharge occurs in 100% of cases only for through defects or defects close to it. It can be passing through the insulation cracks, holes, "stripping" and conducting inclusions. The question arises: is it possible to detect not only through defects by electrosparking control (air pockets, thinnings, cuts, undulations, buildups, etc.)? It is obvious that there is a minimum insulation thickness in which an electrical breakdown will occur during the control. Thickness of breaking defective insulation areas depends on the design of controlled cable products insulation material, technological features and control modes. The above factors influence estimation and examples of calculations of maximum thickness breaking defective insulation areas are given in the article.

3. Experimental part

The electric field distribution in the insulation defect such as a "crack" is shown in the figure 2.

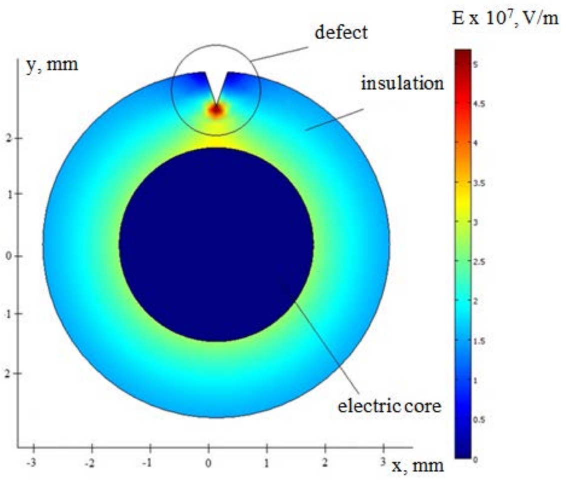

Figure 2. The electric field distribution in the insulation defect such as a "crack".

The basis for the breakdown of non-through defects under the electrosparking control is a heat balance violation in insulation.

As a result of studies a thermal model of the defective area has been proposed. The model main point consists in the defective area initial state and the control conditions comprehensive analysis. In consequence of local overheating a thermal breakdown occurs [14]. The main functional connections describing the process are given below.

$$h_d = \frac{U_{test}}{E_d(h, T, tg\delta)}, \tag{1}$$

$$\Delta T / t_{test} = \frac{U^2_{test} \omega C_{def} tg\delta}{cm}, \tag{2}$$

In the given equations E_d is an insulation dielectric strength determined as a function of the insulation radial thickness h, the actual temperature T, and the dielectric losses $tg\delta$.

It is determined that depending on the control conditions and the material properties the insulation heating rate is equal to (0.3 ÷ 25)˚C/sec. The results of the defective areas overheating rate calculation are shown in the Table 1.

Table 1. Overheating rates of defective areas.

Insulation material, cable product brand	h_d/h, mm/mm	$\Delta T/\Delta t$, º C/sec
PVC plasticate, MGShV-0.35	0.14/0.62 = 0.23	13
Polyethylene, SIP-3	0.29/2.25 = 0.13	0.26
Rubber, APVR	0.33/1.2 = 0.28	25

In this calculation the initial average dielectric temperature T_1 = 60˚C, after cooling bath. The test voltage frequency f_{test} = 1 kHz, the test voltage application duration t_{test} = 10 msec.

The above information allows us to conclude that at high-speed control, at voltage application times approximately equal to several units - tens of milliseconds, insulation overheating does not exceed a few degrees and has no significant effect on the insulation dielectric strength, and therefore on the detection of defective areas with insulation thin layers probability. In case of the control at low speeds at voltage application times more than 1 second significant overheating occurs in the insulating materials with high dielectric losses. Overheating leads to decreasing dielectric strength, up to the possibility of breakdown and defect-free insulation inflammation, for example, insulation made of rubber or some brands of PVC plasticate.

The through defect minimum size is calculated (figure 3) which can be detected by means of the electrosparking control method. Obviously, there is a through defect with extremely small cross-sectional area of the conducting channel which will not be detected.

Figure 3. Example of a through defect.

An example of a through defect in the insulation made of rubber with resistance equal at least to 10^{10} Ω, 10^{14} Ω for polyvinylchloride and not less than 10^{15} Ω for polyethylene is considered. Based on the existing standards requirements [1–7] it is necessary to achieve the defects detector operation threshold at the controlling voltage U = 3 kV and the current through the defective area I = 600 µA. In this case a surface insulation resistance of not more than 5 MΩ (R_{surf} = 5 MΩ) must be provided. The controlling voltage U = 3 kV corresponds to the insulation thickness h = 0.25 mm. The tested material is the rubber with the lowest surface resistance. The circumference of a circular shape through defect when the desired resistance can be reached is equal to $l_c = \rho\cdot(h/R_{surf})$ = 0.5 mm. The hole diameter d_{def} = 0.16 mm.

The calculation of the defect smallest diameter at the electric discharge is given below. A glow discharge occurs at current values up to $I = 10^{-3}$ A. The glow discharge is characterized by a high voltage between the electrodes. The current density in the glow discharge reaches $J = 10^6$ A / m^2. Thus to achieve the defect current level I_{def} = 600 µA a hole diameter of at least d_{def} = 28 µm is required. At larger values of the controlling voltage the discharge current in defects increases and the glow discharge grows into an arc discharge. During the arc discharge the current density is in the range $J = (10^{12} \div 10^6)$ A/m^2 and characterized by a low voltage between the electrodes.

Comparing influencing factors the surface resistance and discharge in the air gap it can be concluded that in order to reliable detection of the through defects in the cable product insulation its diameter should be not less than 30 µm. The surface resistance almost has no effect to the defects detection.

4. Conclusion

Despite the widespread use of electrosparking control in the cable industry there aren’t quantitative and qualitative assessments of defects detected by this type of control [1, 2, and 15].

In the above paper a method of estimating defects on three factors of the electric field and the insulation defective area interaction, such as thermal breakdown, capacitance and dielectric losses control as well as the partial discharges level control, is proposed.

The through defects or defects with the dielectric residual layer is not more than 30% of the defect-free value can be reliably detected by means of the electrosparking control. The minimum diameter of the through holes which can be detected by this control is equal to 30 µm.

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