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Efficiency of cable insulation control in weak and strong electric fields

Cable manufacture is currently one of the most dynamically developing fields of industry. The quality of the cable product must be in compliance with the regulatory documentation to provide reliable transmission path. The quality of cable insulation (continuity and external geometry) is one of the most important control-required parameters. This parameter is particularly significant for communication cables transmitting information.

According to the current regulatory documentation, the control of cable insulation quality is carried out by electrospark and electrocapacity methods. The electrospark method is used for a strong electromagnetic field, and insulation breakdowns are registered during control. The electrocapacity method is used for a weak electromagnetic field. Change in the capacitance is recorded. The method of electrocapacity control in a strong electric field was offered in previous papers.

To compare the efficiency of measurement in strong and weak electric fields the effect of the defect dimension on the capacitance is to be explored in both methods.

Measurement of capacitance in a strong electric field differs from that in a weak electric field due to the electrical breakdown. In case the isolation thickness reduces more than the limit value, the electrical (and/or thermal) breakdown occurs in a strong electric field, whereas in a weak electrical field this does not occur. As the capacitance does not depend on the voltage value, the defect dimension effect on capacitance is the same in both of the methods if the insulation thickness does not exceed the limit value. This statement does not work for the “air pocket” defect because of the electrical discharge occurring in case high test voltage is applied [2]. This phenomenon cannot be observed in a weak electric field.

Different dependencies have been obtained for strong and weak electric fields during exploration of the “air pocket” defect dimension effect on the change in electrical capacitance.

To simplify the plate capacitor with anisotropic dielectric was used. The parallelepiped with *a*x*b*x*c* dimensions (height, length, width, respectively) is the model of the defect (Fig. 1).

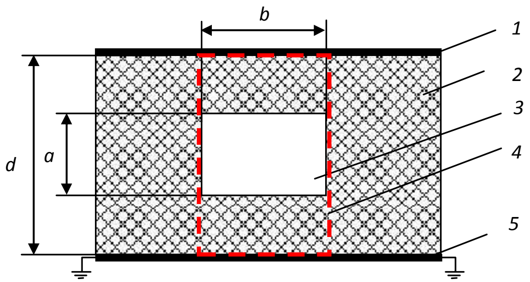

Fig. 1. Defective cable insulation model with an“air pocket” defect:
1 is an electrode (plate of capacitor); 2 is a dielectric;

3 is “air pocket” (defect); 4 is the border of the defective insulation area 5 is a core (capacitor plate)

The electrical equivalent circuit of the defective insulation area with *d*x*b*x*c* dimensions is connected in series to the “air pocket capacity” (C_a) and the insulation capacity (C_i) with (*d*-*a*)x*b*x*c* dimensions. The final defective area capacitance (C_d) is found by with the formula of the electrical capacitance of the plate capacitor [2]:

$$C_d = \frac{C_a \cdot C_i}{C_a + C_i} = \frac{\varepsilon_0 \cdot \varepsilon_r^{\mathrm{a}} \cdot \varepsilon_r^{\mathrm{i}} \cdot b \cdot c}{\varepsilon_r^{\mathrm{a}} \cdot (d-a) + \varepsilon_r^{\mathrm{i}} \cdot a}, \qquad (1)$$

where $\varepsilon_r^{\mathrm{i}}$ is insulation permittivity;

$\varepsilon_r^{\mathrm{a}}$ is air permittivity.

The formula (1) demonstrates the dependence of the final defective area capacitance on the defect dimension in measurement performed in a weak electric field (Fig. 2).

High intensity electric discharges occur in the “air pocket” defect in measuring in a strong electric field, and the defect area can be considered as a high conductive one (Fig. 3).

On the basis of the above, the function of the defective area capacity from the defect dimension is:

$$C_d = \varepsilon_0 \cdot \varepsilon_r^{\mathrm{i}} \cdot b \cdot c / (d-a) \qquad (2)$$

The formulas (1) and (2) were analysed and the dependencies were found to be considerably different.

To verify the theoretically-obtained statement the insulation section model was made in software COMSOL Multiphysics is a plate capacitor with double-layer dielectric (PVC and air). The capacitance calculation was provided with the known formula $C = Q/U$ [1]. The charge (Q) was defined with the Gauss theorem in an integral form [1].

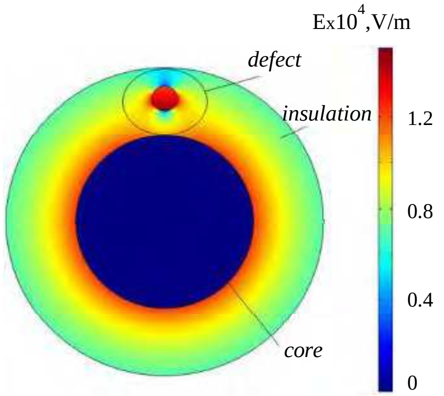

Fig. 2. Tension distribution in cable in a weak electric field (“air pocket” insulation defect)

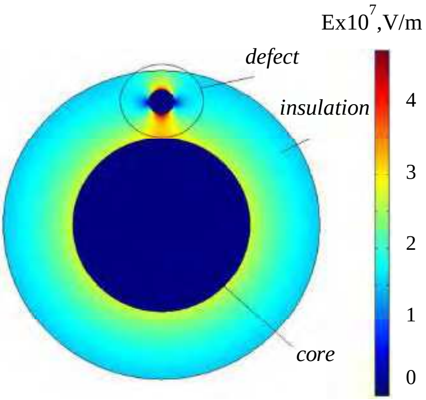

Fig. 3. Tension distribution in cable in a strong electric field (“air pocket” insulation defect)

According to the dependences lines plotted in Fig. 4, it can be pointed out that the dependence in weak electric field differs from that in a strong electric field: the defect capacity slightly decreases as the defect dimension in a weak electric field increases, however this function exponentially increases in a strong electric field.

To define the change in the insulation section capacity the coefficient with a defect (C_d) and without it (C_0) (sensitivity) an additional sign k is introduced:

$k = C_0/C_d$ for a strong electric fields measuring;

$k = C_d/C_0$ for a weak electric fields measuring.

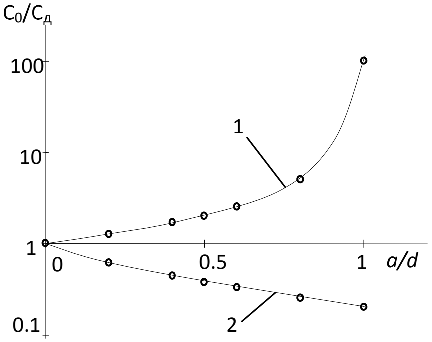

Fig. 2. Dependence of relative capacitance on the relative defect dimension in strong (1) and weak (2) electric fields

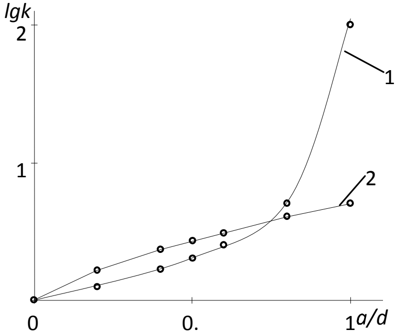

Fig. 3. Dependence of measured sensitivity on the relative defect dimension in strong (1) and weak (2) electric fields

The analysis of the obtained values revealed that higher sensitivity of measuring in a weak electric field in comparison with the sensitivity measured in a strong electric field occurs until the defect dimension does not exceed 70 % from defect-free insulation (Fig. 5). If the defect is large in size, the measurement sensitivity is higher in a strong electric field, and this parameter increases exponentially.

References

1. Govorkov V.A. Electric and magnetic fields. Moscow: State Energy Publishing, 1960. 462 p.
2. Starikova N.S., Redko V.V. Research of the possibility of cable insulation quality technological control with electrocapacity method // IME: compendium III Scientific and Practical Conference / ed. A.V. Yurchenko, Tomsk, 3-5 May 2012.Tomsk: TPU, 2012. Pp. 136-141.

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