The analysis of factors affecting the quality of cable insulation control carried out with the complex method

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Abstract: - To prevent mass spoilage and considerable expenses of producer it is necessary to provide high quality insulation control during the cable manufacture. Current methods of in-process cable insulation control do not provide high quality of control separately. We present a complex method of cable insulation control, which allow us to combine the current methods constructively and increase quality of control. This method consists in measuring of the cable insulation capacity per unit length with applying of high test voltage. To develop the complex method of cable insulation control we carry out analysis of different parameters of technological process affecting the control results such as test voltage parameters, value of electric field intensity, material, temperature of insulation, state of insulation surface, process conditions of production line and offer the ways of decreasing these influences. The results of aforementioned research we present in this paper.

Key-Words: -Insulation, cable, breakdown, capacity per unit length, spark testing, test voltage.

1 Introduction

Insulation is required constructive element of electrical cables and wires. It is used for preventing electrical contact between conducting parts of cable, ensuring the transfer properties of a cable, protecting of cable wire against mechanical influence and another negative conditions. Thus, to provide reliable transition path it is necessary to carry out the high-quality cable insulation control for the whole of cable.

In the current regulatory documentation two methods of control are described such as spark testing [1, 2, 3] and measuring of cable insulation capacity per unit length [4, 5, 6].

The first method consists in passing of controlled cable through the spark tester electrode with applying of high test voltage. If an insulation defect is passing through the controlled area the breakdown will be occurred. That is registered with the automatics [7,8]. Given method have certain disadvantages. This method does not allow us to determine defects such as local enlargement of insulation, thinning of insulation (by less than 70% of defectless part thickness). Thus, given method of control is able to detect only defects which significantly decrease electrical strength of cable insulation.

In the second method the cable insulation capacity per unit length is measured with the special cylindrical electrode. This electrode is immersed in the water of a cooling bath and the controlled cable is passing through the electrode. The water of cooling bath provides an electrical contact between the measuring electrode and cable insulation surface. If insulation defect is passing through the controlled area the insulation capacity per unit length will change. Described method allows detection of the defects which lead to significant deviation of electrical capacity per unit length. Cracks and cuts of insulation cannot be registrated with this method. To perform given control method additional instrumentation and technical maintenance are required for correct functioning of control system.

Both of these methods can not allow registration of all type of insulation defects separately [9, 10], thus the new complex method of cable insulation control is offered. This method is combination of these two methods that allow increasing the quality of control.

This paper is organized as follows. In section 2 we present major information about current methods and about the complex method of cable insulation in-process control, its advantages in comparison with the current methods. The significance of in-process cable insulation control with high quality is presented in section 3. In the next section we describe the theoretical model of the complex method and define differences between the theory and practice. In the section 5 we present analysis of the factors influencing the control result and offer the ways of detuning. Finally, in section 6 we present the directions for future work.

2 The Complex Method of Control

In this new method of in-process control the high alternating test voltage is applied to the cable insulation surface with the bead chain electrode and the cable insulation capacity per unit length is measured at once. The value of test voltage is selected according to the insulation thickness and material as for the spark testing [7, 8, 11]. Thus, the insulation defects are registered in accordance with changing of the cable insulation capacity per unit length and occurrence of electrical breakdown.

3 The Purposes of the Research

Increasing of measurement quality during the manufacture allows you to register an insulation defects on the intermediate not on the final stage of cable manufacture. Defect registration on the intermediate stage of cable manufacture allows operator to avoid mass spoilage due to changing the process conditions at time. Different parameters of technological process affect the results of electrical capacity measurements with the complex method of control. The purpose of this paper is determination of factors affecting electrical capacity measurement and evaluation of its influences. To enhance quality of control the methods for decreasing of the influencing factors is offered.

4 The Theoretical Model of the Complex Method

The complex method is carried out with applying of a high test voltage to a cable insulation surface. Core of the controlled cable remain grounded [12] till test voltage is applied to the cable insulation surface (Figure 1). Electrical contact between the electrode and a cable insulation surface is provided by high-intensity sliding discharges occurring in a strong electric field. An applied alternative test voltage allows measuring of the insulation impedance per unit length.

In this case a cable can be represented by two concentric cylinders. The electrical capacity of a controlled cable insulation area can be calculated with the known formulae for cylindrical capacitor [13]. In practice the measured electrical capacity of cable insulation area differs from the theoretically calculated because of sliding discharges which extend controlled area. Thus, the controlled area L (Figure 1) is longer than a length of electrode applying the test voltage.

5 The Factors Influencing on the Control Results

Developing the complex method of cable insulation control it is necessary to consider the influence of different factors such as test voltage parameters, value of electric field intensity, material, temperature of insulation, state of insulation surface, process conditions of production line on control results.

5.1 The Effect of Test Voltage Parameters

The value of the test voltage for spark testing is significantly higher than the running voltage. The value of test voltage is regulated by the Russian State standards and international documentations [1, 7, 8, 14, 15] in accordance with an insulation

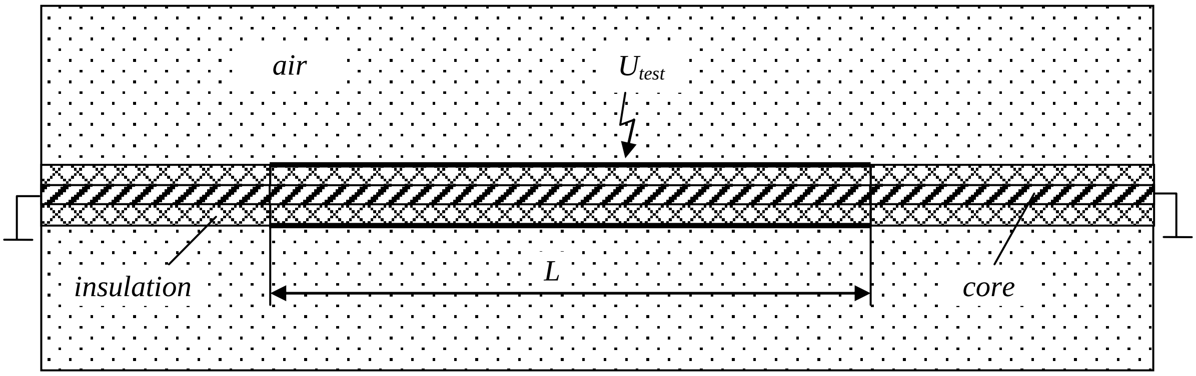

Fig. 1. Model of the controlled area

thickness and material. When the high test voltage is applied to the surface, a sliding discharge is occurred due to considerably non-uniform electric field in control area [16]. The length of a sliding discharge can be calculated with empirical Tepler's formulae [17]:

$$\Delta l = k \cdot C^2 \cdot U^5 \sqrt[4]{\frac{dU}{dt}}$$

Where k is the empirically determined factor, C is the specific surface capacity.

The prolongation of controlled area is the length of a sliding discharge. To define the influence of a value and a frequency of high test voltage on the prolongation of the controlled area length (Δl) the experiment was carried out.

5.1.1 The Experiment

To perform the experiment segment of defectless cable with PVC insulation and 2 ring electrodes were used (Figure 2).

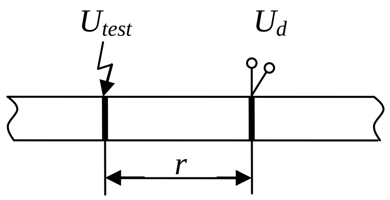

Fig. 2. Dependence of the length of the sliding discharge from the value the test voltage for different values of frequency

Test voltage (U_{test}) was applied to insulation surface with the first ring electrode in the point with zero coordinate. Electric potential (U_d) on the surface was measured with the second ring. The distance between the rings (r) is gradually been increased until the point with zero potential. As a source of test voltage Tabor WW5061 signal generator with Volta-PA-1200 power amplifier and ZNOL-06/20 high voltage transformer were used. Textronix P6015A oscilloscope divider and LeCroy WJ314 digital oscilloscope were used for measurements.

5.1.2 Results

As a result of the experiment the distribution of voltage along the surface was obtained with U_{test}=15 kV (Figure 3).

After numerical processing and analysis of analogous dependences for other values of test voltages the dependence of prolongation of the controlled area length from voltage value and frequency was defined. According to the data obtained it can be noted that increasing of the test voltage value and the frequency leads to increasing of the value Δl (Figure 4).

To decrease the influence of these factors the software of the device has to take into account the value and a frequency of the test voltage.

5.2 The Effect of State of Cable Insulation Surface

To evaluate the length of the controlled area it is necessary to consider the effect of talc (only for rubber insulation) and moisture on the surface of the cable insulation products as well.

During the research of the effect of talc on the control results the relevant literature was analyzed in which the authors solved a similar task [18, 19]. It has been found that talc (in the absence of moisture)

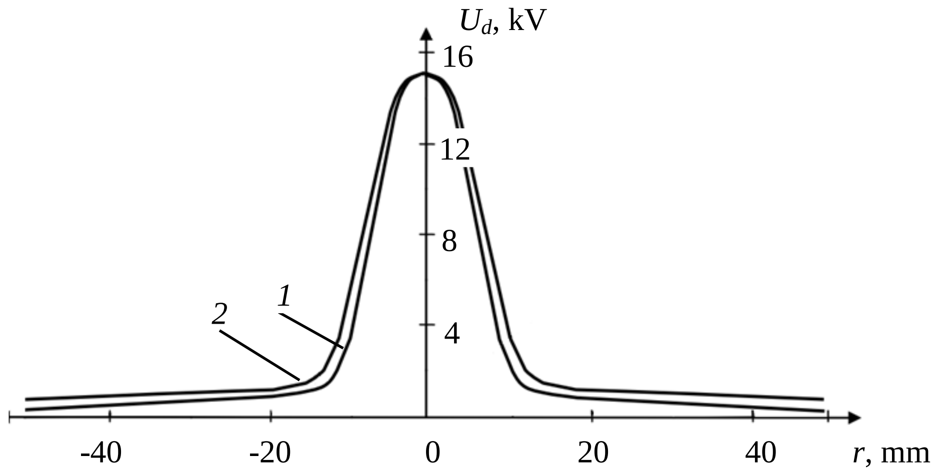

Fig. 3. Distribution of the test alternating voltage along the PVC insulation surface with frequency 50 Hz (1), 1 kHz (2)

has no significant influence on the processes occurring during the control in strong electric fields. Thus, the influence of this factor can be neglected.

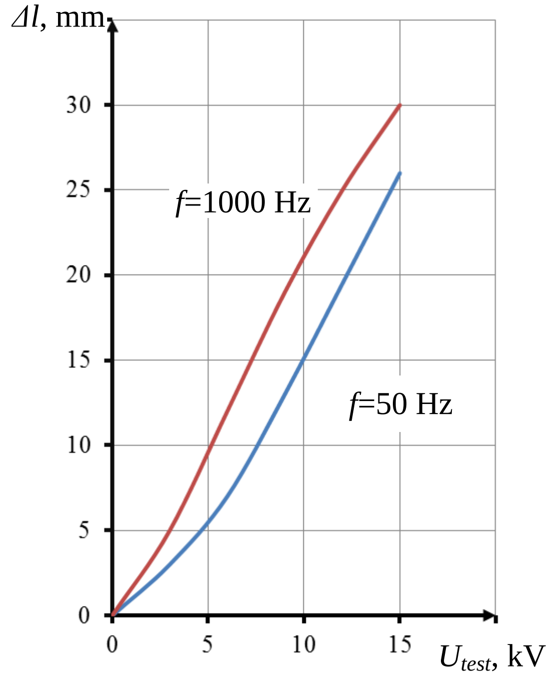

Fig. 4. Dependence of the length of the sliding discharge from the value the test voltage for different values of frequency

To reduce the effect of wet insulation surface on the length of the controlled area prolongation should be considered in the software.

The cable insulation surface becomes wet after extrusion line because at this stage of production insulation is deposited on core by an extruder, after which the cable passes through the cooling bath. After the cooling bath a cable insulation control such as spark testing is provided. Devices for cable insulation control are also placed at other stages of the cable products manufacture for intermediate and output tests such as marking, twinning, taping, bunching, cabling, jacketing, and repackaging [20, 21], at which the surface of the cable insulation remains dry. It has been experimentally proved that prolongation of the controlled area for dry and wet insulation differs approximately in two times at the same test voltage and electrode length. Thus, for quality recording of insulation capacity per unit length the expected state of insulation (dry or wet) have to be pointed in software.

5.3 The Effect of Value of Electric Field Intensity

The main materials used as cable insulation are polymeric materials such as polyvinyl chloride (PVC), polyethylene (PE), fluoroplastic. These materials are linear dielectrics [22], consequently their dielectric permittivities are constant and independent of the electric field, so the effect of this factor can be neglected.

5.4 The Effect of Material and Temperature of Insulation

Cable insulation temperature is not constant at different stages of the cable production and affects the dielectric constant (respectively, and capacity per unit length).

On the output of the extruder the temperature of the insulation is about 100°C, after passing through the cooling bath the insulation temperature is reduced to 40-50°C [23]. As mentioned before, the cable insulation control is carried out immediately after insulation depositing. At other stages of the cable production, where cable insulation control is required, heating is not provided. An average annual ambient temperature at the maintenance workshop is approximately 20°C. Thus, it is necessary to consider the insulation temperature variation in the range from 20 to 50°C.

Analyzing the literature on issue of temperature affecting the dielectric constant [24, 25, 26] written by Russian and foreign researches we make up a conclusion that the dielectric constants of insulation materials have weak temperature dependence in considered temperature range. Thus, the influence of this factor can be neglected. Type of insulation material has to be pointed out in software of device.

5.5 The Effect of Process Conditions of Production Line

According to the technology of cable production a cable is always in motion. Linear speed of production lines is determined according to the required operation mode. At high velocity of production lines the radial vibration of controlled object often occurs. It is also the cause of a noise in the measurement of cable insulation capacity per unit length. The maximum permissible deviation of the object from the central position is regulated by the normative document MD 16 14.640-88 in Russia and it equals 10 mm. In practice, this deviation equals 1..5 mm. To decrease the influence of this factor it is possible to use a digital filtering of the measured signal. Filtration is advantageously carried out with a fast Fourier transform, which allows removing of the low-frequency component due to mechanical vibrations of the cable product from the spectrum of the received signal.

6 Conclusion

In this paper we offer the new complex method of cable insulation in-process control, which provide higher quality of control and do not require additional maintenance in comparison with the current method of cable insulation in-process control, such as spark testing and measuring of cable capacity per unit length. To develop the complex method of cable insulation control it this paper it was found that such factors as the parameters of the test voltage, temperature, moisture and insulation material of cable products have a significant influence on the result of measurement of the cable insulation electrical capacity per unit length. The effect of the electric field intensity and the presence of talc on the surface (for rubber insulation) on the measurement results are insignificant and do not require detuning.

Using the proposed methods to reduce the influence of these factors will increase the quality of the cable insulation control. The proposed methods are software-based and do not lead to construction complication, and, thus, to a cost increasing.

In future work we are planning to develop the numerical model of controlled cable area with using finite element analysis program. It allows us to research the efficiency of control using different type of electrodes and to define the appropriate constructive parameters of the electrode.

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References:

[1] GOST (State standard) 2990-78: *Cables, wires and cords. Methods of voltage testing*, Moscow: standards Publishing House, 1986.

[2] D. Carroll, How to choose the best spark tester for your application: AC vs. DC, Clinton Instrument Company. Available at: http://www.cicsparkers.com/wp-content/uploads/2011/11/AC-vs-DC-press-release.pdf (Accessed 28th of December 2015).

[3] H. Prunk, Latest development in measuring equipment for online quality control at the cable extrusion, Proceedings of the 69th Annual Convention -Wire and Cable Technical Symposium (WCTS); Atlanta, GA, USA,1999, pp. 378-385.

[4] A.E. Goldstein, G.V. Vavilova, Deviation from the impact of changes in the electrical conductivity of water on the results of the technological control capacitance per unit length of the electric cable, *Polzunovsky Gazette*, No.2, 2013, pp.146-150.

[5] Patent № 2358928 GB, IPC G01B 7/06. A system for monitoring fluctuations in the thickness of a cable insulating sheath / Patrick Fleming, Lee Robert Coleman.; appl. 04.02.2000; published 08.08.2001.

[6] GOST (State standard) 27893-88: *Telephone cables. Test methods*, Moscow: Standartinform, 2010.

[7] IEC 62230: 2006: Cables, wires and cords. Spark testing method, Moscow: standards Publishing House,2012.

[8] GOST R 54813-2011: *Cables, wires and electrical cords. Spark testing method*, Moscow: Standartinform, 2012.

[9] N.S. Starikova, V.V. Redko, Research on the reliability of monitoring the integrity of the insulation on the electrical capacitance change in the strong electric fields, *Proceedings Non-destructive testing*, 2013, Tomsk, pp. 153-159.

[10] V.V. Redko, L.A. Redko, N.S. Starikova, Increase the information content electric-process control of insulation of cable products, *Polzunovsky Gazette*, No.2, 2013, pp.164-167.

[11] GOST (State standard) 23286-78: *Cables, wires and cords. Standards of insulation thicknesses, covers and test voltage*, Moscow: standards Publishing House,2008.

[12] H. Clinton, Grounding of conductors during the spark test, *MEASURING & TESTING*. Available at: http://www.cicsparkers.com/wp-content/uploads/2011/11/Grounding-Conductors.pdf (Accessed 15th of December 2015).

[13] V.A. Govorkov, Electric and magnetic fields, Moscow: State Energy Publishing, 1960, 462p.

[14] BS 5099:2004. *Electric cables – Voltage levels for spark testing*, Incorporating Amendment No. 1, 2005, 7 p.

[15] UL 1581. *Reference Standard for Electrical Wires, Cables, and Flexible Cords*, 2006, 238 p.

[16] V.I. Merkulov, Numerical modeling for insulation constructions, Tomsk: TPU, 2001, 156 p.
[17] D.V. Razevig, High Voltage Equipment, Moscow: Energy, 1976, p.471.
[18] V.F. Vazhov, High Voltage Equipment. Guidelines for laboratory work, Tomsk: TPU, 2006, 79 p.
[19] A.N. Grigoriev, A.V. Pavlenko, A.P. Ilin, E.I. Karnauhov, The electrical discharge on the surface of a solid dielectric. Part 1. Features of development and the existence of a surface discharge, *News of TPU*, №1, 2006, pp. 66-69.
[20] V.V. Redko, L.A. Redko, Yu.G. Gladyshev, High voltage insulation test DC voltage "KORONA-PN", Proceedings of Scientific and technical problems and Instrumentation Engineering: the Russian scientific and technical conference 2004, Tomsk, pp. 55-58.
[21] Insulated Wire & Cable: Clinton Instrument Company. Available at: http://www.cicsparkers.com/industries/wire-cable/ (Accessed 10th of November 2015).
[22] B.M. Tareev, Physics of dielectric materials, Moscow: Energoatomizdat, 1974.
[23] V.M. Leonov, I.B. Peshkov, I.B. Ryazanov, S.D. Holodnyi, Fundamentals of cable technology, Moscow: Academy, 2006, 432 p.
[24] Y.V. Koritskii, V. V. Pasynkova, B. M. Tareev, Handbook of electrical materials, Volume 1, 3rd ed., Moscow: Energoatomizdat, 1986, p. 368.
[25] Vijayalakshmi Rao, P. V. Ashokan, J. V. Amar, Studies on Dielectric Relaxation and ac Conductivity of Cellulose Acetate Hydrogen Phthalate–Poly (vinyl pyrrolidone) Blend, *Journal of Applied Polymer Science*, Volume 86, Issue 7, 2002, Available at: http://onlinelibrary.wiley.com/doi/10.1002/app.11074/pdf.
[26] Omed Gh. Abdullah, Dana A. Tahir, Shuja-Aldeen B. Aziz, Optical and electrical properties of polyvinyl-chloride (PVC) films, *Iraqi Journal of Science*, Volume 51, No2, 2010, pp. 25-300.