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ROLE OF INSULATION WRAPPING ON HV ELECTRODE IN THE MECHANISM OF ELECTRICAL DISCHARGE DEVELOPEMENT IN TRANSFORMER OIL

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The results of research intended to reveal the role of insulation wrapping on HV electrode in the mechanism of electrical discharges in transformer oil under lightning impulse are presented in this paper. This role is determined by the analysis of the parameters characterizing the discharges and also by observation of their spatiotemporal development and oscillograms of the light emitted by their channels. The research was carried out for two model electrode configurations: an electrode with paper insulation and a bare electrode which had the same outer geometric dimensions as the insulated one.

1. INTRODUCTION

Electrical discharges in dielectric liquids have been a subject of studies for many years. The most applicable of these liquids is transformer oil on which an essential part of investigations has been concentrated. The discharges in transformer oil have been investigated using mainly bare electrode set-ups of highly non-uniform fields (point-plane geometry) [1, 3, 7]. Such configurations, although very useful from the experimental point of view, do not have a significant practical reference because in currently used insulation structures electrodes are always covered with paper and the field is at least quasi-uniform. For this reason a set-up of insulated electrodes was selected as a subject of the research. It may be assumed that the insulation wrapping in the setup of paper covered electrodes has a prime significance in the processes both of initiation and propagation of the electrical discharges. The voltage drop on this insulation wrapping may not be measured directly – it can be inferred by an analysis of the parameters characterizing the discharges (propagation velocity, onset voltage, time to initiation) and observing the shape of the discharge forms, and also the light emitted by the discharge. The effect of the paper wrapping may be revealed by comparison of the aforementioned parameters of the discharges initiated and developing in the same field conditions between bare and insulated electrodes. This is only possible if both the electrodes have the same outer dimensions and when the inter-electrode distance is the same [2, 4, 5].

2. EXPERIMENTAL SYSTEMS

The research was performed in a laboratory, which consists of two cooperating experimental systems. The first one took photographs of the discharges. It uses the single-shot shadowgraph method in which a Q-switched YAG neodymium laser was used as a flash lamp. The 10 ns wide and 20 mJ strong infrared impulse generated by this laser was than converted into its second (green) harmonic – it enabled recording both slow and fast discharge in satisfactory resolution. The second one employed a Hamamatsu R1925 photomultiplier tube and a digital storage Tektronix TDS 3052 oscilloscope of the sampling rate up to 5 Gs/s to record the light impulses emitted by the developing discharges. Both systems worked simultaneously. The train of light impulses from the PM tube, after having been amplified, was fed into a Detector of Discharge Initiation (DDI); the first of them activated the Detector. The DDI output impulse tripped the DSO and, after a predetermined time lag, also the Q-schwitched laser. All the controlling and measuring devices were housed in a Faraday cage with an efficient power filter – their communication with outer units was provided using light guide links.

As a voltage source, the six-stage Marx generator of rated voltage 500 kV and stored energy of 2,2 kJ, was used. It produced 0,83/50 μs lightning impulse [4, 5].

3. METHODOLOGY OF RESEARCH

The HV electrodes of both types used in the experiments are shown in Fig. 1.

a) b)

Fig. 1. HV electrodes used in the experiments: a) paper covered one, b) bare one

The values of individual parameters of discharges (onset voltage, time to initiation, propagation velocity, rise time of light pulses), for both the model electrode configurations and polarity of the impulse voltage were estimated using methods of statistical analysis [6]. The values of those parameters were compared and then correlated with discharge photographs and light oscillograms. The measurements and the estimations of the discharge parameters for the bare electrode were taken additionally at the voltage equal to the mean value of the onset voltage of the group of insulated electrodes.

4. RESULTS

The similarities between the discharge forms developing from both types of electrodes can be easily seen from Fig. 2 and Fig. 3.

a) b)

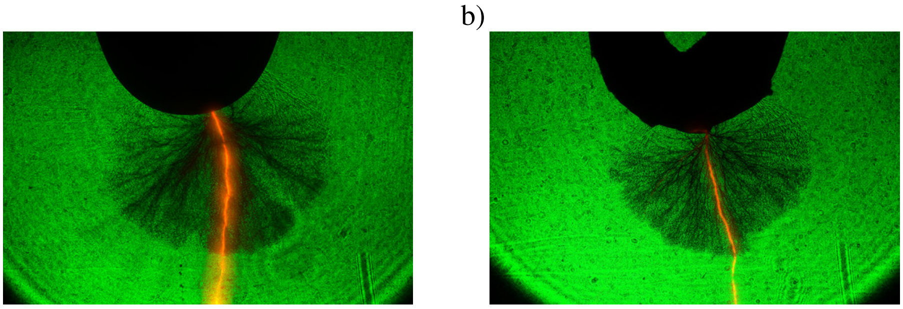

Fig. 2. Exemplary photos of positive discharges: a) developing from bare HV electrode, U_p = 189,6 kV, b) developing from insulated HV electrode; U_0 = 189,6 kV

a) b)

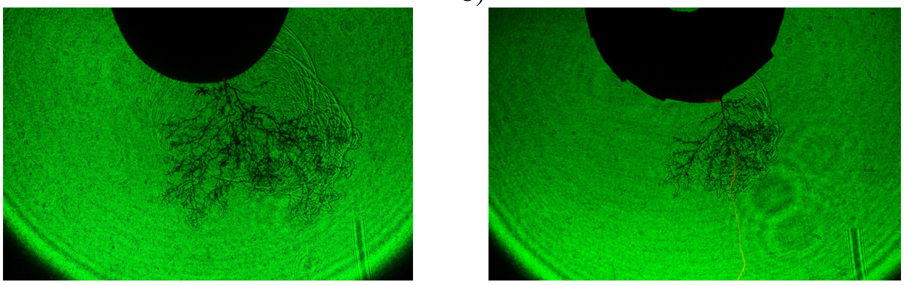

Fig. 3. Exemplary photos of negative discharges: a) developing from bare HV electrode, U_p = 192 kV, b) developing from insulated HV electrode; U_0 = 192 kV

HV electrode insulation wrapping's influence on the electrical discharge initiation and development in transformer oil related to the estimated parameters of discharge was considered in four aspects:

- change of the light impulses shape and their characteristic times,
- hindrance of the initiation processes, which must occur in weak points in oil (or insulation wrapping), not on the surface of the metal,
- increase of the onset voltage of the discharge as a result of shoving away the onset sites out of the high field strength region,
- slowdown of the discharge channel development as a consequence of limitation of the discharge current by the capacity of insulation wrapping.

The first refers to the shape of a single light impulse i.e. its rise-time. No difference was observed in the average values in both cases. The impulses have identical shapes and the calculated average rise-times are practically identical (Tab. 1).

Table 1. Average rise-times $\bar{t}_n$ of light pulses and their confidence intervals (normal distribution)

Polarity of lightning impulse	Bare electrode		Insulated electrode	
	$\bar{t}_n$ [ns]	Confidence intervals [ns]	$\bar{t}_n$ [ns]	Confidence intervals [ns]
+	4,4	$3{,}9 < \bar{t}_n < 5{,}5$	4,3	$3{,}9 < \bar{t}_n < 5{,}6$
-	4,5	$3{,}7 < \bar{t}_n < 5{,}7$	4,4	$3{,}4 < \bar{t}_n < 5{,}6$

The second aspect concerns discharge initiation. The results of the measurements of times to initiation for bare and insulated electrode performed at the same test voltage lead to a conclusion that the oil, not the surface of the electrode or the insulation wrapping, is the "tank" of the discharge initiation sites.

Table 2. Average times to initiation $\bar{t}_d$ and their confidence intervals at the same value of test voltage (lognorm distribution)

Polarity of lightning impulse	Bare electrode		Insulated electrode	
	$\bar{t}_d$ [μs]	Confidence intervals [μs]	$\bar{t}_d$ [μs]	Confidence intervals [μs]
+	4,99	$4{,}18 < \bar{t}_n < 6{,}19$	4,96	$4{,}40 < \bar{t}_n < 5{,}65$
-	4,66	$3{,}75 < \bar{t}_n < 6{,}17$	4,56	$3{,}83 < \bar{t}_n < 5{,}55$

These times are almost identical, so they are not influenced by the structure of the surface on which the onset sites originated. The possibility that both physically so different surfaces could be equally productive sources of initiation sites is hardly probable [2, 8].

The third aspect is related to onset voltage (U_0). It is obvious that the insulation must increase U_0 and it really is the case (from about 150 kV to 190 kV – see Table 3) but not to the level of 173 kV. This difference is accompanied by a difference in times to initiation: the higher U_0 value corresponds to the shorter time to initiation. These differences are logically correlated if the initiation is considered in terms of most stressed oil volume law.

Table 3. Average values of onset voltages (Weibull distribution) and times to initiation ((lognorm distribution)

Electrode type	$\bar{U}_0$ [kV]		$\bar{t}_d$ [μs]	
	+	-	+	-
electrode stripped of its insulation wrapping	148,8	148,8	--------	--------
insulated electrode	189,8	192,1	4,96	4,56
bare electrode	173,2	173,4	8,69	5,15

The discharge onset voltage for the insulated electrode is higher than for the bare one, meanwhile, the time to initiation is shorter. It is not possible, on the grounds of investigations, to indicate the cause of the differences.

The fourth aspect is related to propagation velocity. For both electrode configurations and both polarities of test voltage, no significant differences were observed in average propagation velocities. This is particularly evident when we consider the propagation velocity of channels which develop at the same test voltage. The ratio of those velocities was 0.97 for positive discharges and 0.96

for negative ones. Insulation wrapping does not slow down discharge channels. Therefore, the voltage drop on it from discharge currents is so low that it cannot hinder their development.

The clear differences which prove the influence of insulation wrapping on the mechanism of electrical discharge development in transformer oil can be seen on oscillograms of light emitted by the discharges (Fig. 4). First of all, a lower frequency of light pulses can be noticed in the case of discharges developing from insulated electrodes. This can be explained in the following way.

a) b)

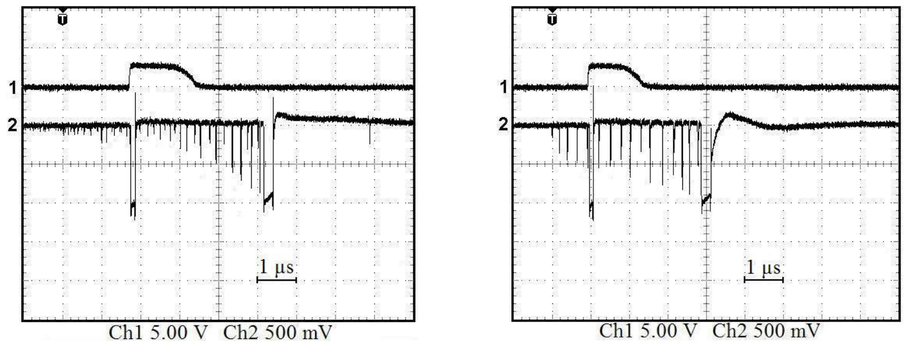

Fig. 4. Exemplary oscillograms of light emitted during the discharge:
a) bare HV electrode, b) insulated HV electrode

Each flash of discharge channels leaves charge carriers of both polarities in the inter-electrode space; those having the sign of the HV electrode are repelled by field forces while those with the opposite chargesettle on the electrode surface. Reignition of the streamers requires restoration of the former field strength on the electrode surface; its actual value depends not only on the instantaneous value of the test voltage but also on surface and space charge densities and the distance of the latter from the HV electrode surface. Both the charges lower the geometric field. A time lag to restoration of the reignition conditions depends on rate of the surface charge decay and, at least in the initial stages of discharge, on the actual position of space charge cloud. The observed differences between light oscillograms of the discharges developing from both the types of electrodes are due to the above mentioned action of the charges. In the former case the surface charge is quickly neutralized, in the latter having no direct contact with the metal, they have to be dissipated by diffusion or removed by tangent component of the field. The conditions for the reignition are thus restored sooner when the HV electrode is bare then when it is insulated – that is why the time distances between the neighbouring impulses are shorter for the bare electrode. These times of discharge inactivity decide how far the space charge is repelled into the bulk of oil away from the electrode surface. This distance is obviously shorter for the bare electrode. The space charge handicaps the development of the reignited discharge i.e. degree of its ramification; this influence is the more efficient, the closer to the electrode surface the charge is positioned. It may be thus concluded that the light impulses referring to the bare electrode must be lower than the ones resulting from the discharges from the insulated electrode and it may be clearly seen in Fig. 4, at least at the discharge stage close to the onset. The differences between crest values of the light impulses tend to decrease with increasing discharge range because the field forces causing relocation of the space charge are lower in this highly non-uniform field and their effect becomes less important when discharge gets closer to a grounded electrode.

5. CONCLUSIONS

There are four possible roles, enumerated in Chapter 4, the insulation wrapping plays in discharge onset and development; analysis of the investigation outcomes has made it possible to reduce their number and, hence, to prove the first thesis of the PhD work: "Onset mechanism of electrical discharges on HV electrode surface does not depend on whether it is insulated or not. The role of insulation wrapping is only to shove away the onset sites out of the region of high field strength and thus to raise the onset voltage".

Analysis of the light impulse time trains has proved the second thesis: "The spatiotemporal development of the discharges from the insulated electrode is controlled by the surface charge reducing the field strength on the discharge site and the space charge reducing degree of channel ramification".

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ROLA OTULINY IZOLACYJNEJ NA ELEKTRODZIE WN W MECHANIZMIE ROZWOJU WYŁADOWAŃ ELEKTRYCZNYCH W OLEJU TRANSFORMATOROWYM

Streszczenie

W artykule przedstawione zostały rezultaty prac badawczych nad rolą otuliny izolacyjnej na elektrodzie WN w mechanizmie rozwoju wyładowań elektrycznych w oleju transformatorowym pod wpływem napięcia udarowego piorunowego. Ta rola została określona poprzez analizę parametrów wyładowań rozwijających się w oleju, a także poprzez obserwację ich rozwoju czasowo-przestrzennego oraz oscylogramów światła przez nie emitowanego. Badania przeprowadzono dla dwóch modelowych układów elektrod: elektrody pokrytej otuliną izolacyjną i elektrody gołej o tych samych wymiarach zewnętrznych jak elektroda z izolacją. Wnioski zawarte w dwóch tezach, które udowodniono w pracy można sformułować następująco:

1. Mechanizm inicjacji wyładowań elektrycznych na powierzchni elektrody wysokonapięciowej jest taki sam bez względu na to czy elektroda jest goła czy też pokryta otuliną izolacyjną. Rola otuliny izolacyjnej polega jedynie na odsunięciu miejsc inicjacji z obszaru silnego pola i powiększeniu napięcia inicjacji wyładowania.

2. Czasowo-przestrzenny rozwój wyładowań od izolowanej elektrody jest narzucony przez ładunek powierzchniowy osłabiający pole w miejscu zapłonu oraz ładunek przestrzenny ograniczający intensywność rozgałęziania się kanałów.

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