The Surface Discharge in Electrode System with Potential Barrier

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At present, gas-discharge generators based on surface discharge are used in various fields of technics and technology [1-5]. Due to the significant non-equilibrium of gas medium and the high electron concentration ($n_e \leq 10^{18}$ cm^{-3} [1]), the surface discharges are unique plasma source. The surface discharge includes low-current and high-current stages [1, 6]. In the high-current stage, the glided sparks are able to ionize large volumes of gas providing the glow discharge generation at the atmospheric pressure [1, 6]. However, an ablation and erosion of dielectric layer initiated by the glided sparks shorten the life time of gas-discharge devices in practice [6]. On the other hand, for devices based on low-current surface discharges, there is a need to increase the area of the plasma sheet and to enhance discharge power [7-8]. Thus, it is necessary to study the features of the low-current plasma electrodes in order to increase their power without gas breakdown along dielectric surface.

It is well known [8-9] that surface discharges generated by aperiodic voltage pulses leave natural charges on the surface of a dielectric substrate. The presence of residual surface charges on the dielectric layer significantly changes the characteristics of the surface discharge. In this case, the accumulated surface charges are able to limit the inter-electrode gap breakdown as well as to enhance surface discharge current [8]. Therefore, the artificially-deposited surface charges make it possible to control the discharge process intensity without high-current discharge stage formation.

Investigation of surface discharge formation on the charged dielectric layer was carry out in electrode system presented in Fig.1. The electrode system provided the surface discharge

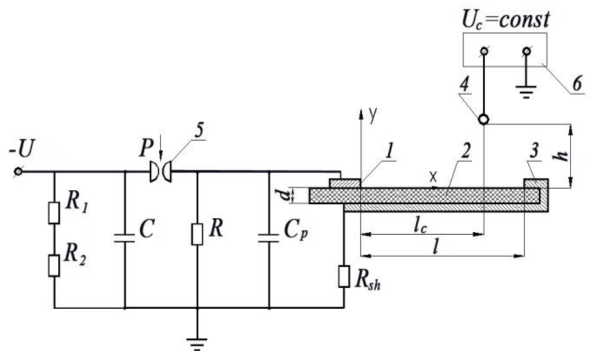

Fig.1. Electrode system for the surface discharge excitation on the charged dielectric layer: 1- high-voltage electrode, 2- dielectric layer, 3-grounded electrode, 4-corona electrode, 5-high-voltage discharger (РУ-67), 6 – high-voltage source. Electric parameters of scheme: C=30 nF, C_p=0.8 nF, R<150 Ohm. Geometric parameters of scheme: *l = 40mm*, l_C *=15mm*, *d= 0.8 mm.*

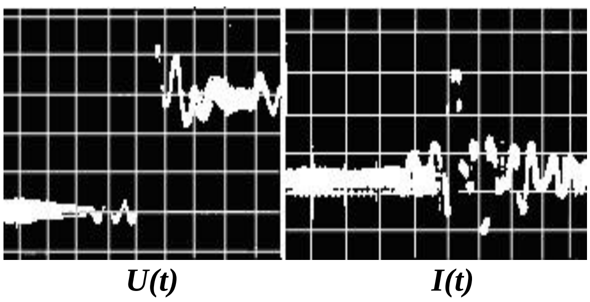

Fig.2.Oscillograms of voltage and current for surface discharge on the charged dielectric layer. Typical scales: voltage – 4.2 kV/div, current – 200A/div, time 100 ns/div.

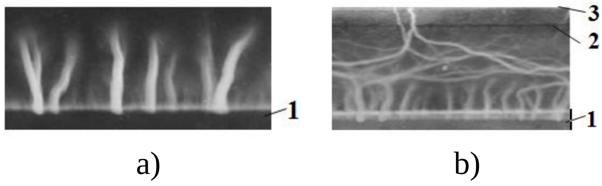

Fig.3. Visualization of the surface discharge formation in the mono-pulse (a) and frequency (b) generation modes on the charged dielectric. 1-high-voltage electrode, 2 –corona electrode, 3- grounded electrode.

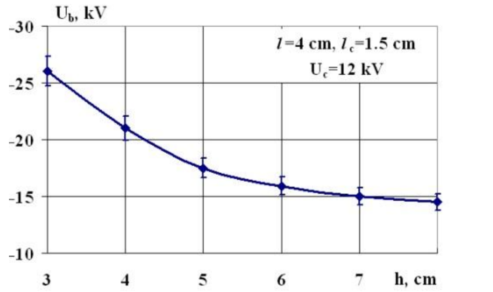

Fig.4. Breakdown voltage (U_b) of the surface inter-electrode gap vs. corona electrode height (h).

generation under a aperiodic voltage pulses action (see Fig.2). Such voltage pulses had short front (dU/dt≅10^{12} V/s). In the electrode system, the surface charges were deposited by subsidiary corona electrode (with diameter around 100 μm) on the kapton, film-type, dielectric layer. The deposited charges formed potential barrier which limited propagation surface discharge along dielectric.

During operation, corona discharge was initiated under potential U_c which was less than the high-voltage electrode potential U. In Fig.3, the surface discharge was formed under condition $|U_c|\cong 0.5\text{-}0.6\cdot|U|$. This condition provided an increase in the gap breakdown voltage by a factor of 1.5-2 (see Fig. 4). Breakdown voltage growth was especially revealed in the case of the mono-pulse excitation of the discharge (see Fig.3a). While the frequency discharge generation mode due to additional deposition of charges on the dielectric led to the partial neutralization of potential barrier by leader channels propagated in parallel to corona electrode (see Fig.3b).

This mechanism was confirmed by electrographic and probes diagnostic methods [8]. It was shown (see Fig.5) that with the voltage growth (U) on the high voltage electrode, the surface discharge front interacted with the potential barrier boundary. At $U>U_{(b)}$ (see Fig.5c), the discharge

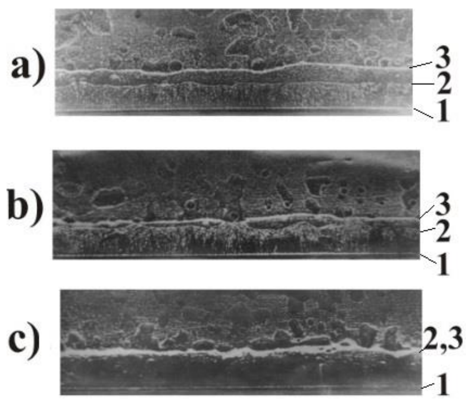

Fig.5. Electrographic visualization of 'charge to discharge' interaction under surface discharge excitation: 1-high-voltage electrode, 2- surface discharge front, 3-potential barrier front. $U_{(a)}<U_{(b)}<U_{(c)}$.

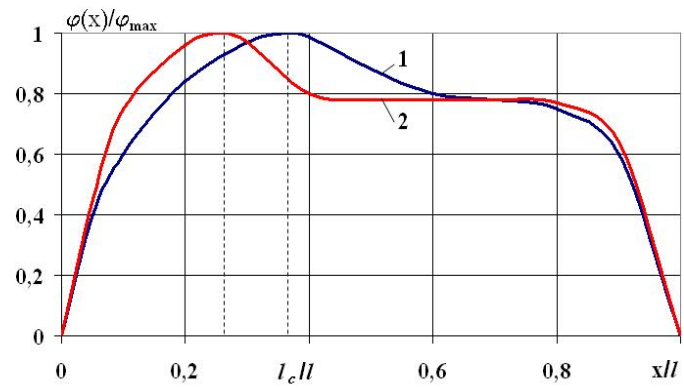

Fig.6. Potential distribution into inter-electrode gap:
1 - potential distribution before surface discharge excitation,
2 - potential distribution after surface discharge propagation.

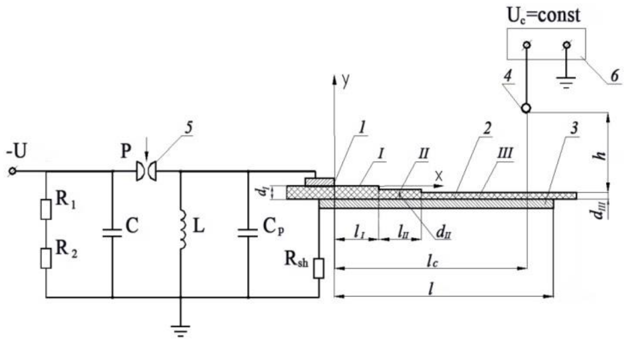

Fig.7. Electrode system for Hybrid Surface Discharge excitation: 1- high-voltage electrode, 2- profiled dielectric substrate, 3-grounded electrode, 4-corona electrode, 5-high-voltage discharger (РУ-67), 6 – high-voltage source. Electric parameters of scheme: C=30 nF, C_p=0.8 nF, L<11μH. Geometric parameters of scheme: $l_I = l_{II}$, $l_C = 6\cdot l_{II} = 60mm$, $l - l_C = l_I$, $d_I = 3d_{III}$, $d_{II} = 2d_{III}$, $d_{III} = 0.8$ *mm.*

penetrated into the zone of the corona-deposited charges. It redistributed the deposited charges on the dielectric surface and led to the potential gradient growth at the boundary of the charge relief (see Fig.6). The electric field enhancement at the boundaries of the charge relief created conditions for the discharge of the surface charges from the dielectric layer to the high-voltage and the grounded electrodes as it was illustrated in Fig. 3b.

In order to enhance the process for the discharge of charges from the dielectric surface to metal electrodes, an electrode system with the profiled dielectric substrate (see Fig.7) was developed. In the electrode system, the profiled dielectric substrate had the following functions. According to [8-9], the thick dielectric part of the substrate under the high-voltage electrode facilitated the propagation of plasma channels along dielectric in the first period half while the thin dielectric part of the substrate under corona electrode increased the deposited charges density.

According to Fig.7, inductance (L<11μH) in the electric circuit provided the surface discharge excitation under the alternative voltage action. The electrode system generated the damped voltage fluctuations with a period T<5 μs and a damping decrement of 2 (see Fig.8). Under alternative voltage action, the first period half provided the surface discharge interaction with potential barrier while second period half created conditions for charges neutralization on the profiled surface of dielectric substrate.

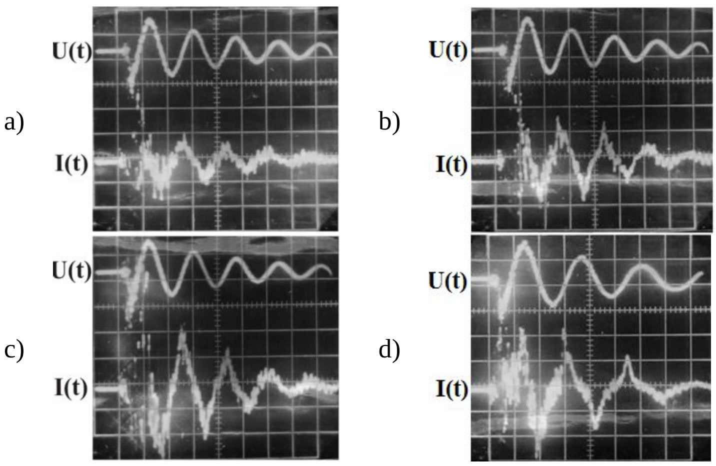

Fig.8.Oscyllographic properties of Hybrid Surface discharge: (a) U=-25kV, U_C=0, L=2.5 μH; (b) U=-25kV, U_C=-10 kV, L=2.5 μH; (c) U= U_C =-25kV, L=2.5 μH; (d) U= U_C =-25kV, L=4 μH. Typical scales: voltage – 10.5 kV/div, current – 50A/div, time - 1 μs/div.

As a result, the Hybrid Surface Discharge (HSD) was formed in the inter-electrode gap with current amplitude of 2 times higher than that in the ordinary, low-current, surface discharge (compare Fig.8a and Fig.8c). Fig.9 demonstrates HSD-formation at the different discharge modes. The

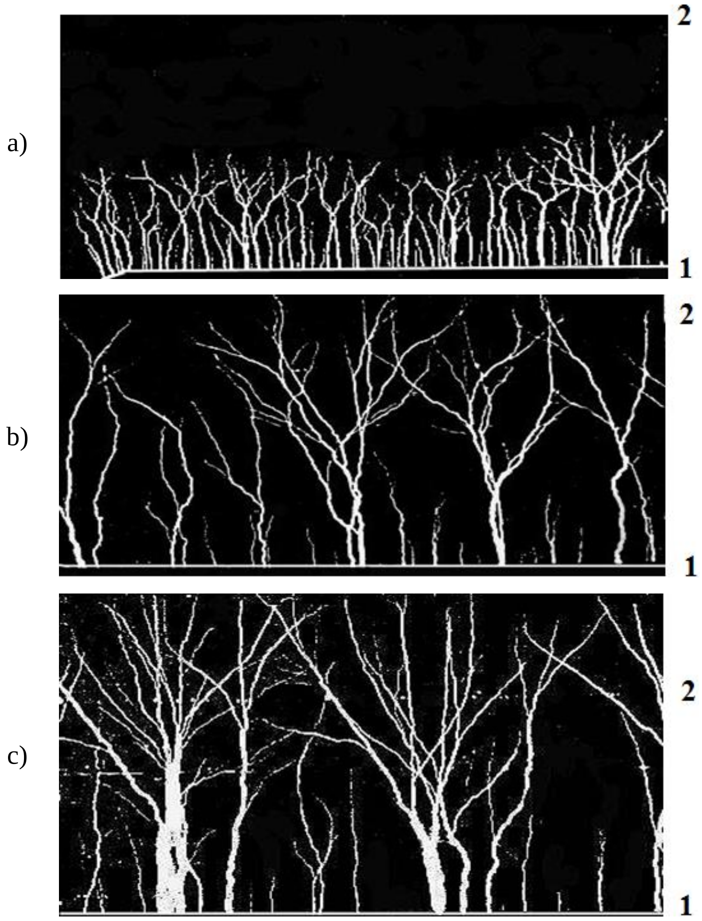

Fig.9. Hybrid surface discharge generation modes at U=-25 kV and L=4μH: (a) - U_c=0, (b) - U_c=-9kV, (c)- U=-19kV. 1-high-voltage electrode, 2- corona electrode.

photographs show an increase in the plasma channels length (up to 70 mm in Fig.9c) as well as intensification of plasma radiation with voltage growth on the corona electrode. The branching of the plasma channels at such intensity confirms the discharge transformation to the leader stage.

Operation of the electrode system (Fig. 7) with the frequency up to 10 Hz did not lead to visible erosion of the dielectric surface. Such result indicates that plasma electrodes based on Hybrid Surface Discharge may be used in different types of gas-discharge generators and plasma technologies.

Acknowledgement

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