Union of Electronics, Electrical Engineering and Communications
Technical University of Sofia
EAZ Inc. — Plovdiv
House of Science and Technology— Plovdiv
IEEE Bulgaria Section

XIII-th International Symposium on Electrical Apparatus and Technologies

SIELA 2003

PROCEEDINGS

Volume II

29 – 30 May 2003
Plovdiv, Bulgaria

ISBN 954-90209-2-4

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* In additional appendix to volume II.

CONDITIONS FOR AN ELECTRIC RESONANCE IN VARIOUS TECHNOLOGICAL REGIMES OF THE LOW-FREQUENCY CAPACITIVE DISCHARGE

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Abstract. The highest technological effectiveness of the low-frequency capacitive discharge at atmospheric pressure is observed under the conditions of serial electric resonance in its electric circuit, when an additionally adjusting capacitor is connected in series with the working gap of plasma generator. In these conditions maximal active electric power is transferred from the mains to the electric discharge; at the same time this power being a measure for the occurring plasma-chemical changes during surface modification.

In the various technological regimes of burning of the low-frequency capacitive discharge there are created diverse conditions for the manifestation of serial electric resonance for the electric discharge circuit represents a linear resonance system with multiple degrees of freedom.

Keywords: external (volt-ampere) static characteristic, high-pressure low-frequency discharge, plasma-chemical surface modification, surface power density, voltage or serial resonance, degree of freedom.

INTRODUCTION

The high-pressure low-frequency capacitive (*LF-CD*) discharge is an autonomous electric discharge, that is burning owing to the presence of a series capacitive ballast reactance introduced in the external electric circuit of the discharge in order to limit the electric current of the *LF-CD* discharge [1].

The variety of elementary plasma-chemical processes that define the existence of a *LF-CD* discharge at high pressure and low frequency (50/60 Hz) is very great and presupposes the existence of an electrical oscillatory system, which includes the discharge itself, with many degrees of freedom or with many frequencies of natural oscillations. The voltage of burning of the *LF-CD* discharge does not depend on parameters of the external electric (force) action, i. e. on the effective value of the voltage U_{eff}. The external force action is realized from a source of voltage in the conditions of a serial resonance or the so-called electric resonance of voltages.

Investigations on the *LF-CD* discharge, which use the external static volt-ampere characteristic, demonstrate the existence of two differentiated technological regimes of discharge burning: *the first* of them being characterized by the existence of ozone- and oxygen-containing cold plasma, and *the second* one being characterized by the existence of a plasma that contains nitrogen oxides.

THE TASK of the present work consists in examining the conditions that exist in the two technological regimes of burning of the *LF-CD* discharge at atmospheric pressure for the realization of a resonance of voltages in its electric circuit. The surface density of the active electric power is perceived as an indicator of technologically effective resonance regimes of burning of the *LF-CD* discharge.

CONDITIONS FOR THE OCCURRENCE AND EXISTENCE OF AN ELECTRIC RESONANCE

The *LF-CD* discharge is an autonomous electric discharge characterized by the fact that the electric current is limited by connecting a capacitive ballast reactance C_I in the external circuit of the discharge. The capacitance C_I is the capacitance of the "sound" air gap of the corona discharge, capacitance of the barrier located in the air gap, or capacitance of the ballast capacitor connected in series into the circuit of the capacitive electric discharge, Fig. 1.

The adjustment of the electric discharge circuit into a serial resonance is performed by including the set of capacitors, the capacitance C_A of which can be changed in steps, Fig. 1.

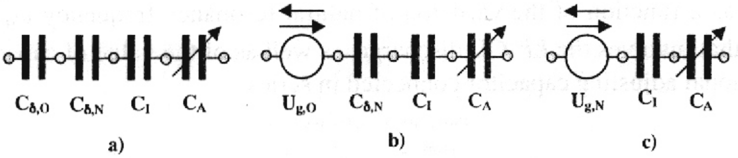


Figure 1. Equivalent circuits for the various development stages of *LF-CD* discharge: **a** –pre-discharge stage being a non-operating regime; **b** - discharge stage based on the plasma-chemical behavior of oxygen or first operating regime; **c** - discharge stage based on the plasma-chemical behavior of nitrogen or second operating regime.

The discharge gap is represented by the two capacitor $C_{\delta,O}$ and $C_{\delta,N}$ connected in series, which correspond to the plasma-chemical behaviors of oxygen and nitrogen, respectively, and the source of voltage, the value of which, $U_{g,O}$ or $U_{g,N}$, does not depend on the voltage applied, U_{eff}, Figs. 1b and 1c. The difference between the two regimes of burning is a result not only of different voltages of burning, but also of the presence of capacitance $C_{\delta,N}$ in the first regime of burning, which modifies the resonance spectrum of *LF-CD* discharge.

The superposition principle is applicable to processes going on in a linear resonance system, which means that the general system reaction to external force action consists of the responses of the multitude of oscillators that constitute it. It is expected that the external static volt-ampere characteristic will represent an enveloping curve of all maxima manifesting themselves during variation of the adjusting capacitance C_A. For a constant frequency of the external force action (50 Hz), the susceptibility of the linear resonance system is changed by varying capacitance C_A of the adjusting capacitor. The parametric resonance allows revealing all degrees of freedom in a resonance system like the electric circuit of the *LF-CD* discharge. This approach takes into consideration the influence of capacitance $C_{\delta,N}$ in the equivalent circuit of discharge gap on the electric resonance in the two characteristic regimes of *LF-CD* discharge burning.

The considerable amount of experimental investigations requires that the examination shall be focused on one representative of the capacitive discharges, namely on the barrier discharge. The barrier discharge burns between two plane electrodes for invariable geometry of the inter-electrode space: constant thickness $\delta = 3$ mm of the barrier (made of alkaline glass) and constant size $b = 3$mm of the working air gap. The plasma generator operates at no load, or no materials for surface plasma-chemical modification, that could influence the discharge electric characteristics, are placed in the working gap. Non-influenced electric resonance characteristics of the *LF-CD* discharge at no load are examined.

EXPERIMENTAL RESULTS AND DISCUSSION

The external static volt-ampere characteristic of the *LF-CD* discharge is plotted experimentally as a function of the variation of natural resonance frequency ω_0 of the electric circuit that involves the *LF-CD* discharge, as well as of the value of capacitance C_A of the additional adjusting capacitor connected in series.

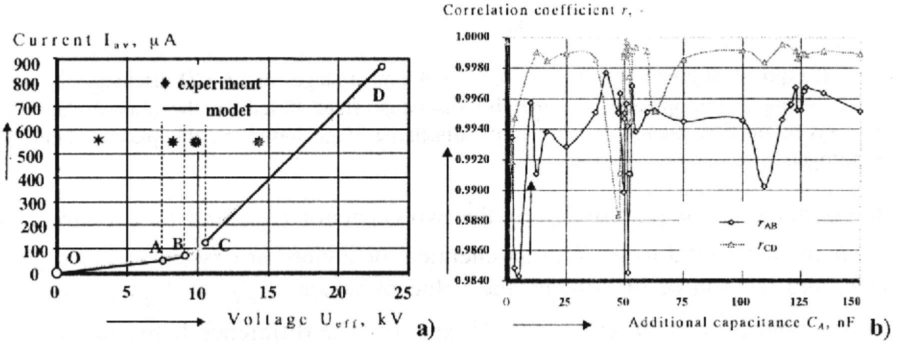
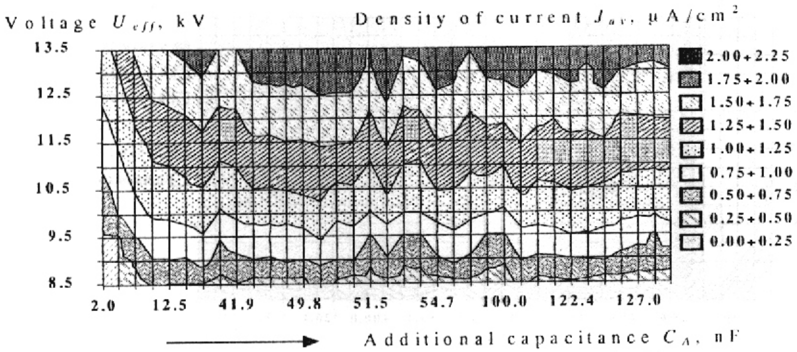


Figure 1. Operating regions of the electric capacitive discharge; the relationship between the average value of current I_{av} and the effective value of applied voltage U_{eff} (**a**): **OA** – non-operating sector; **AB** – first operating sector of the cold technological plasma containing ozone and products of its decomposition; **CD** – second operating sector of the cold technological plasma containing nitrogen oxides; BC - transient region.

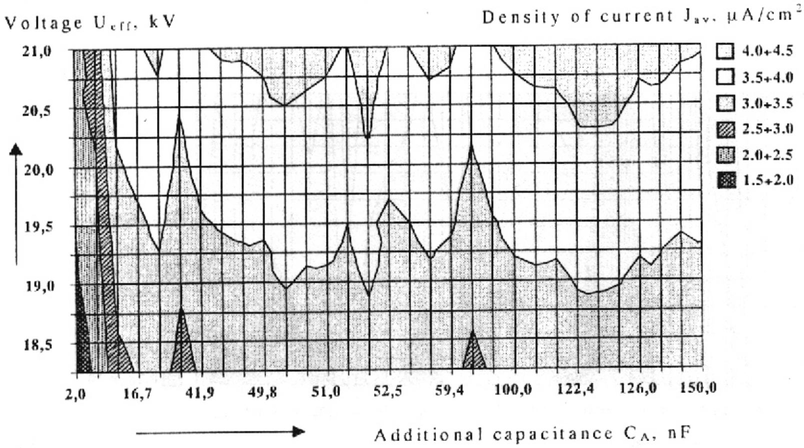
The correlation coefficient *r* of the linear correlation between the variation of current I_{av} and variation of voltage U_{eff} with the value of adjusting capacitance C_A (**b**).

Each of the two operating regions *AB* and *CD* of the external characteristic can be expressed by a linear regression relationship of the type shown in Fig. 1:

(1) $$I_{av} = B_0 U_{eff} + A_0, \text{ for } U_g = |A_0|/B_0 \text{ at } \delta, b = Const \text{ or}$$



a)



b)

Figure 2. Spectral curve of the variation of current I_{av} with the variation of capacitance C_A of the adjusting capacitor as well as with the variation of the natural frequency of the resonance circuit for operating region *AB* (**a**) and operating region *CD* (**b**).

(2) $$J_{av} = B\,U_{eff} + A \text{ , for } U_g = |A|/B \text{ at } \delta, b = Const .$$

This character of the external characteristic presupposes the existence of the following linear relationship for surface density of power p_a:

(3) $$p_a = D\,U_{eff} + C \text{, for } A = D \text{ and } C/D = U_{cr} .$$

The correlation coefficients of linear correlation confirm the relationships described by equations1 ÷ 3, Fig. 1b.

Spectral distributions of current density J_{av}, power factor $Cos\,\varphi$ and surface density of power p_a for the two regimes *AB* and *CD* of no-load *LF-CD* discharge burning are shown in Figs. 2 ÷ 4 for parameters $\delta = 3$ mm and $b = 3$ mm.

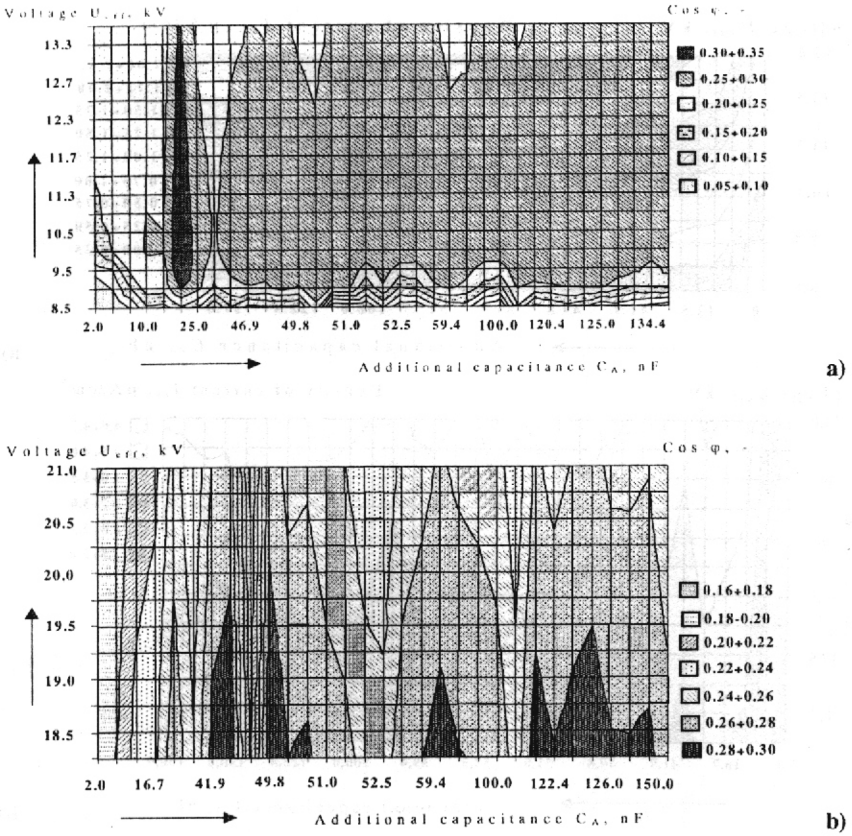


Figure 3. Spectral curve of the variation of power factor *Cos φ* with the variation of capacitance C_A of the adjusting capacitor for the two operating regions *AB* (**a**) and *CD* (**b**) of *LF-CD* discharge burning.

The analysis of results obtained imposes the following principal conclusions:

- the maxima in the two operating regions of discharge burning do not coincide as regards their places on the scale of the natural frequencies (or of the variation of capacitance C_A);
- there are different numbers of maxima as well as there are different maximal surface densities of the active power p_a introduced into the resonance circuit;
- the maximal density of the active power $p_{a,max}$ for the two regions (up to 20 kV) is as follows: up to 550 W/m^2 (with respect to 9.5 W/m^2 at absence of resonance) for ***region AB***, and up to 250 W/m^2 (with respect to 232 W/m^2 at absence of resonance) for ***region CD***;

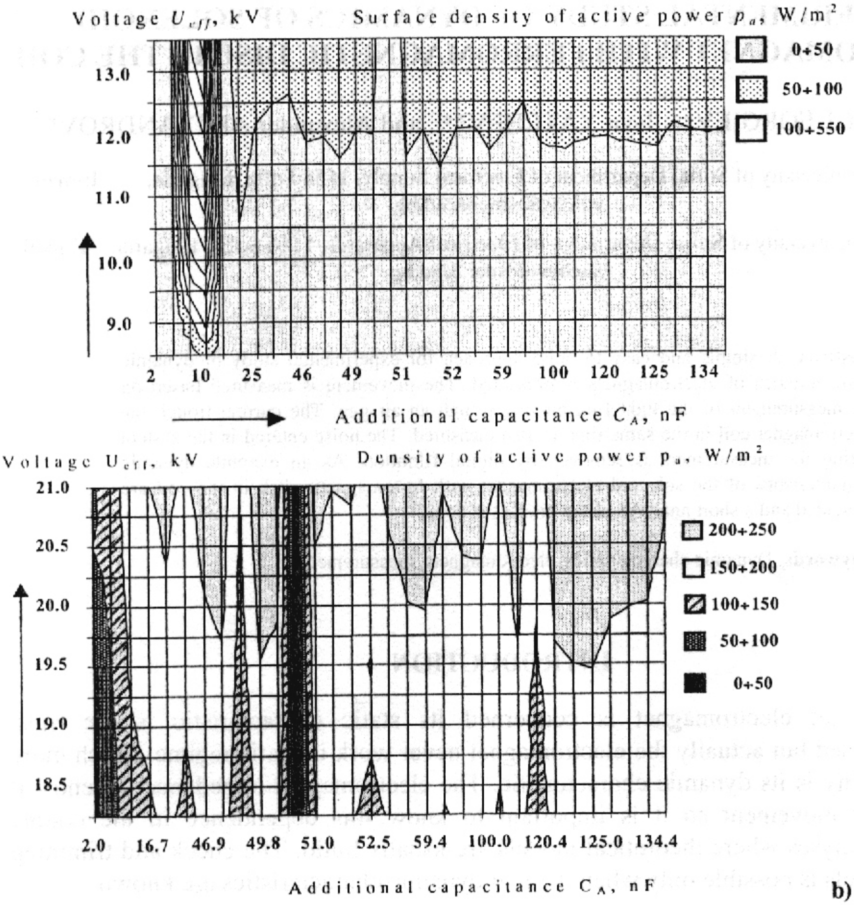


Figure 4. Spectral curve of the variation of the surface density of active power p_a with the variation of capacitance C_A of the adjusting capacitor for the two operating regions *AB* (**a**) and *CD* (**b**) of *LF-CD* discharge burning.

● the maximal (common for all processes or oscillators) power factor $cos\,\varphi_{max}$ is: up to 0.350 (with respect to 0.318 at absence of resonance) for ***region AB***, and up to 0.300 (with respect to 0.318 at absence of resonance) for ***region CD***.

● the maximal density of current $J_{av,max}$ is: up to 2.25 μA/cm² (with respect to 0.63 μA/cm² at absence of resonance) for ***region AB***, and up to 4.50 μA/cm² (with respect to 4.30 μA/cm² at absence of resonance) for ***region CD***.

REFERENCES

[1] P. Dineff. *Electrotechnology: Introduction to Electrotechnology*. Sofia, Bulgaria, TUS, 2001.