Discharge Element with Transverse High-Frequency Excitation

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Abstract – **Recently, the usage of high-frequency transverse discharge in technologies for treatment of liquid fluids presents practical interest because: the discharge is characterized by higher stability; reactive elements can be used as a passive load and efficiency coefficient increases; there is symmetric energy dissipation; electrodes with dielectric coating can be used, which solves the problems with their sputtering.The work is devoted to study of the possibilities for application of single circuit generators with automatic pre-voltage and inductive-capacitive matching converter for excitation of a transverse discharge and control of its parameters according to the technological application.**

Keywords – **single circuit generator, generator with automatic pre-voltage, inductive-capacitive converter**

I. Introduction

The effectiveness of the discharge medium excitation highly depends from the ratio between the frequency of the external field and the frequency of the interaction between the electrons and the atoms and more precisely if the electrons energy succeeds to follow the change of the external field during the oscillationperiod. The characteristic velocity of changing of the electron energy with the change of the field is Eq.(1):

$$f_e \cong k_{ei} n_a m_e / m_a \qquad (1)$$

At high frequencies ($f>>f_e$) the energy of the electrons slightly changes in time. Therefore arise conditions for development of an ionization process with constant velocity during the whole time of discharge existence.

Furthermore, the energy of the electron provides such frequency of ionization that electrons have in the so called constant effective electrical field.

$$E_{eff} = \frac{E_a}{\sqrt{2}} \cdot \frac{\nu_{ei}}{\left(\omega^2 + \nu_{ei}^2\right)^{0,5}} \qquad (2)$$

E_a – amplitude of the field
ω – frequency of the external electrical field
υ_{ei} – frequency of the elastic interactions of the electrons with the neutral atoms;

In case of low frequencies ($f \leq f_e$) the electrons energy “follows” the electrical field. In that case, the discharge in an alternating electrical field remindsconductivity current-dependent discharge with periodic ionization. In force is the exponential character of the dependency of the ionization velocity from the electron energy. Gas ionization is accomplished only in the regions with maximum intensity of the external electrical field, and during the interval between them flows current of the conductivity-dependent discharge inthe decomposing plasma. Typical values of f_e at n_a~10^{18}cm^{-3};k_{ei}~10^{-7}cm^3.s^{-1}; m_e/m_a~10^{-5} are $10^6 \div 10^7$Hz. The amplitude which is necessary for supporting of the high-frequency discharge is defined by the conditions for the balance between generation and recombination of the electrons and it is close to the intensity of the electrical field in direct current discharge.

Near-electrode processes in high-frequency discharge play a relatively minor role than in direct current discharge.

An example realization of a single circuit lamp generator is shown in Fig.1.

The conditions for generator self-excitation and the stability of the steady mode are discussed in [1].

The aim of the present work is study of the possibilities for ensuring of starting and operating modes of the transverse discharge [2], its control and choice of a converter as a matching section for transforming the output voltage of the resonant circuit into current of the discharge element.

II. Analysis

Quadripoles with reactive elements [3] are connectedbetween the load (the discharge element) and the generator. They ensure the following:

- converting of the generator output voltage into constant current through the load according to its specific properties;
- transformation of the active part of the load resistance R_L in resistance of the circuit R_e.

The dependency between the anode voltage U_a and the converter input voltage U_L with a load (the discharge element) is necessary to be found for calculation of the relationship.

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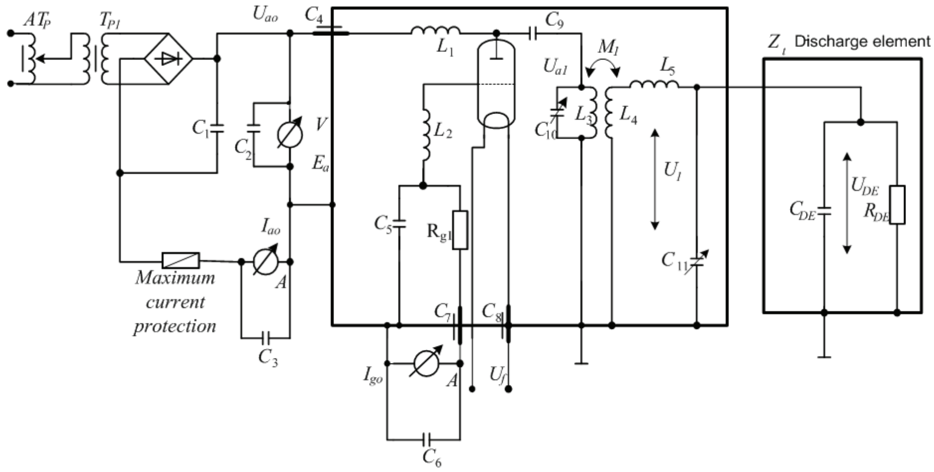


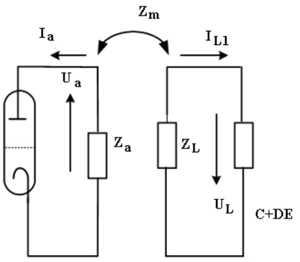
Fig.1. Single-circuit lamp generator

In the presented general circuit of the relationship (Fig.2) Z_a is the impedance of the anode circuit, Z_L – the converter impedance (discharge element),and Z_m is the mutual impedance. C stands for a converter and DE is the discharge element.

Before a discharge occurs in the discharge medium $i_L=0$, the circuit from Fig.2 could be transformed equivalently into the circuit in Fig.3, where Z_τ is resistance at short circuit, which includes also theresistance introduced from the anode circuit. After transformation according to the Thevenin's theorem the scheme in Fig.3 becomes the one, shown in Fig.4.

$$U_{LOC} = \frac{U_a}{Z_a}.Z_m \tag{3}$$

$$Z_\tau = Z_L + Z_{introduced} = Z_L - \frac{Z_m^2}{Z_a} \tag{4}$$



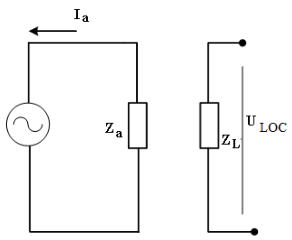
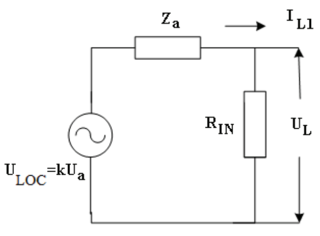


Fig.2 .Fig.3.

Scheme of the relationships and equivalent representation



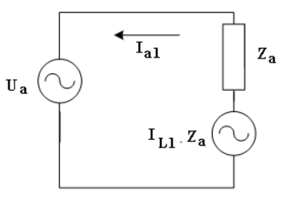


Fig.4. Fig.5.

Equivalent scheme of the anode circuit with consideration of the influence of the converter and the discharge circuit

If we define a transformation coefficient K – Eq.(5), then when load current flows is valid Eq.6:

$$K = \frac{U_{LOC}}{U_a} = \frac{I_{a1}Z_m}{I_{a1}Z_a} = \frac{Z_m}{Z_a} \tag{5}$$

$$U_L = KU_a - I_{L1}Z_a \tag{6}$$

Hence, the influence of the anode circuit on the load is expressed by excitation of electromotive force (EMF) – $k.U_a$ and introducing of additional resistance.

The influence of the load on the anode circuit can be reported by the equivalent circuit in Fig.5 by Eq.(7) and Eq.(8):

$$U_a = I_{a1}Z_a - I_{L1}Z_m \tag{7}$$

$$U_a = Z_a(I_{a1} - KI_{L1}) \tag{8}$$

In steady mode the voltage in the load circuit and the anode voltage of the generator can be given by Eq.(6) and Eq.(8).

In case that K is a real number, Z_a is an imaginary number (Z_a – reactive resistance), where $Z_\tau << Z_a$ and if Z_a is the resistance of a parallel resonance circuit in resonance – $Z_a=R_{EqOC}$at $i_L=0$, then after transformation of Eq.(6) and Eq.(8) for R_e (at $i_L=0$) is valid Eq.(9):

$$R_e = \left(1 - \frac{KI_{L1}}{I_{a1}}\right).R_{EqOC} \tag{9}$$

The last equation considers the change of the resonance resistance of the anode resonant circuit from the work of the discharge element.

The discharge element control suggests necessity from converting of the generator output voltage into current i.e. the voltage source is transformed into a current source.

An example variant of such transformation is shown in Fig.6.

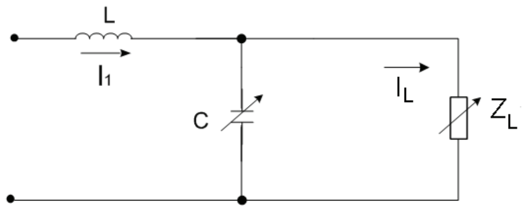


Fig.6. Inductive-capacitive converter

If for L and C is valid $j\omega L = -j\frac{1}{\omega C}$, which is achieved by change of the capacitance C and $u_1 = U_m \sin \omega t$, then the complex value of the load current can be derived from Eq.(10).

$$\overset{*}{I}_L = \frac{-j\overset{*}{U}_1}{\omega L + Z_L(\omega^2 LC - 1)} = \frac{-j\overset{*}{U}_1}{\omega L} \qquad (10)$$

Analyzing the schematic solution from Fig.6, it can be noted that at $Z_L \to \infty$ the system aims at resonance and U_C increases. This favors the rise of a discharge in the discharge medium as the magnitude of U_C is limited by the reduced active resistance, which indicates the losses in L and C as well as the influence of the previous step. At resonance I_1 (Fig.6) increases i.e. according to Eq.(9) R_e decreases, which leads to decrease of U_a and consequently decrease of U_C and I_1.

At Z_L=0, I_1 is limited by the inductive reactance ωL, i.e. this mode does not present any danger.

The linear relationship between the current I_L through the discharge element and U_1 at invariable ω and L without additional compensations means that the instability of I_L doesn't exceed the instability of U_1.

III. Experimental Study

In Fig.7 is shown a prototype of the generator from Fig.1, developed with a lamp (metal-ceramic triode ГИ-7Б) with air cooling. The amplitude of the generated high-frequency oscillation with a frequency of 2MHz can be changed by variation of the anode supply voltage of the lamp generator.

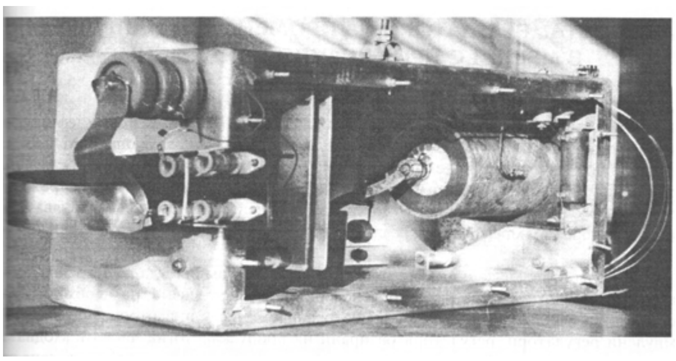


Fig.7. Experimental prototype of a single-circuit lamp generator with a metal-ceramic triode with forced air cooling

The experimental studies have been conducted with an equivalent of the discharge circuit shown in Fig.8.

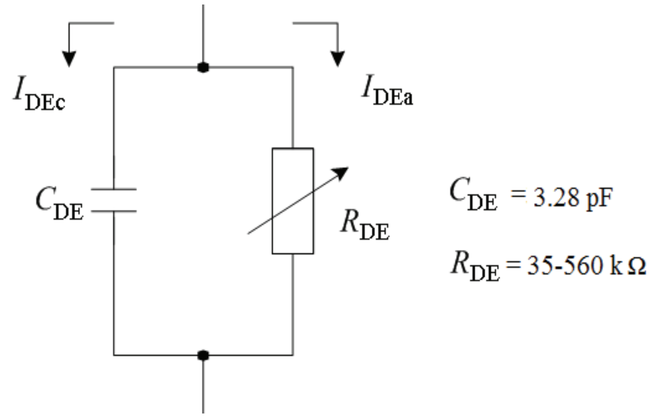


Fig.8. Equivalent representation of the discharge element with transverse high-frequency excitation

At open circuit mode $R_{DE}=\infty$, considering the certain values of L and C in the resonant circuit of the lamp generator and its quality factor, there are achieved values $U_{C_{DE}} = U_{C_{DE}}(2{,}5 \div 4)U_{a1}$ - higher than 14kV.

I_{DEa} (Fig.8) is regulated in the range 25÷100 mA. The achieved maximum power over the load is 350 W.

In the matching impedance circuit the condition $\omega^2 LC = 1$ can be hardly achieved in practice due to a deviation of the generator frequency, the parameters temperature change of L and C and disregard of their parasitic active resistances.

In Fig.9 is shown the change of $\frac{\delta I_{DE}}{I_{DE}} = f_1(A)$ where $A = 1 - \omega^2 LC$ for equivalent R_{DE}=20kΩ and C=3,28pF and R_{DE}=60kΩ and C=3,28pF. The change of A with 20% and R_{DE} – three times – leads to a relative change of I_{DE} not exceeding 20%.

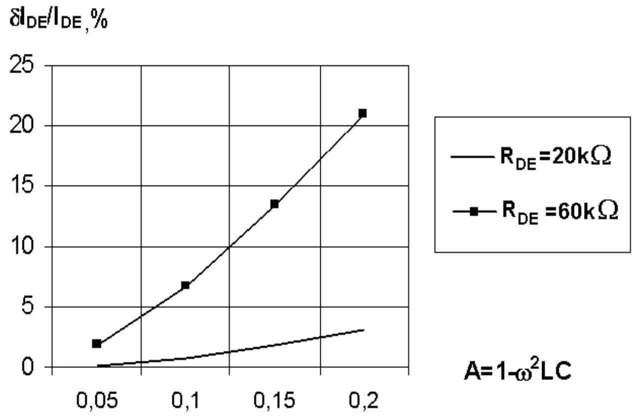


Fig.9. Relative change of the load current as a function of the change of $A = 1 - \omega^2 LC$

IV. Conclusion

It is proposed a variant of a lamp high-frequency generator with a matching section – L-shaped inductive-capacitive converter, which gives the possibility at generated frequency of 2MHz for ensuring starting and operating mode for excitation of a transverse discharge.

The generator provides possibility for fine adjustment of the discharge current in the range of 25÷100 mA at maximum output power 350 W.

The studies of the discharge current stability as a function of the change of the generator parameters and those of the discharge plasma reveal appropriate choice for the matching section.

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