Characteristics of Multi-channel Surface Discharge Switch for High Current Generator

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Abstract – Charging voltage and load inductance influences on switch characteristics were experimentally investigated. Multi-channel surface discharge switch was used as an object of investigation. Impedance, active resistance and inductance were measured for different switch regimes. As a result for used experimental conditions (capacitance C_o = 79 μF, charging voltage U_o = 20…25 kV, circuit inductance L_c = 20…100 nH), for time t = 5…18 μs quasistationary stage was detected. At this stage switch inductance and active resistance of switch are constant.

1. Introduction

Preliminary investigations of physical processes which proceed in the store of electrical energy, in the switch and in the electrical load are required for modern electrophysical plants development. The detailed data on quantitative characteristics of these processes are necessary for that purpose. The switch is a key element determining the process of energy input into the load.

For increasing the rate of energy input into the load, it is necessary to minimize the inductance and active resistance of all elements of the electrical circuit. The switch inductance contribution can achieve ~40% of circuit inductance. The switch energy losses to the time $t \cong T/4$ (the first current maximum) could have value ~30% of the capacitor bank energy. Thus, the switch reduces current amplitude in the load, and reduces efficiency of energy transferring from the capacitor bank to the load. The first and the second problems are closely connected.

Any switch (discharger) has itself characteristic – time of switching – dependence of the voltage across the switch $U_{sw}(t)$ or the switch resistance $R_{sw}(t)$ on time. This dependence is called the characteristic of switching. This characteristics is determined by type of the switch and current flowing through the switch $I(t)$, i.e. $U_{sw}(t)$ depends on charging voltage U_o and the load impedance Z_l.

The multi-spark low inductance dischargers working on a principle of dielectric surface breakdown are often used for construction high current generators. During current commutation switch resistance is significantly changed, passing the range of intensive energy dissipation.

The purpose of this work is to investigate charging voltage U_o and load inductance L_l influences on characteristics of multi-channel surface discharge switch (Z_{sw}, R_{sw}, L_{sw}).

2. Experimental set-up

The spark gap was formed by two basic electrodes (high voltage - 2 and collector - 4) (see Fig. 1). The initiating (trigger) electrode - 3 was connected to a source of initiating high voltage pulses. The total size of the gap was 50 mm. The length of electrode system was 450 mm. The dielectric for surface discharge - 6 was glass-cloth laminate with thickness of 2 mm. The capacity of a capacitor bank C_o was 79 μF (IC-50-3). The cable pulse transformer [1] was used as a source of initiating pulses. The amplitude of initiating pulses was 120 kV, the front duration was 60 ns.

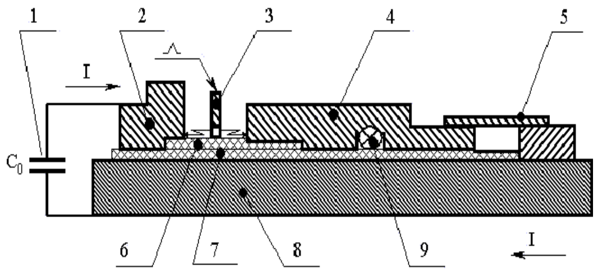


Fig. 1. The schematic image of the experimental apparatus: 1) capacitor bank, 2) high voltage electrode, 3) initiating electrode, 4) collector, 5) equivalent load, 6) dielectric for surface discharge, 7) insulation, 8) electrical pathway, 9) Rogovski coil

Experiments were carried out in two stages. At the first stage the resistive divider with dividing capacity C_i (Fig. 2) was used to measure voltage across the switch $U_{sw}(t)$. A Rogovski coil was used to measure the current $I(t)$ through the switch. The switch impedance in function of time was defined as:

$$Z_{sw}(t) = U_{sw}(t)/I(t) \quad (1)$$

The error of measurements was 10 %.

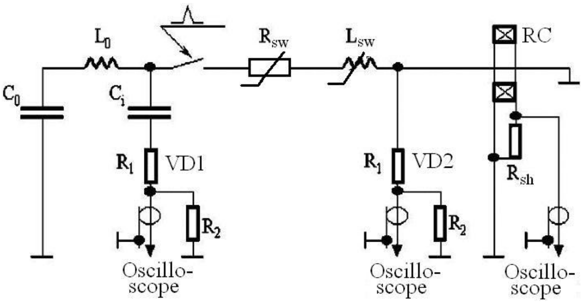


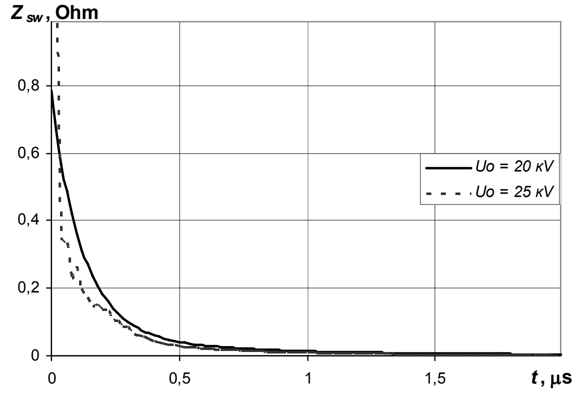
Fig. 2. Electric measurements: C_o – capacity of the capacitor bank; L_o – inductance of a circuit; $R_{sw}(t)$ – active resistance of the switch; R_{sh} – shunt resistance; $L_{sw}(t)$ – inductance of the switch; C_i – dividing capacity; VD1, VD2 – resistive voltage dividers; RC – Rogovski coil

3. Results of experiments

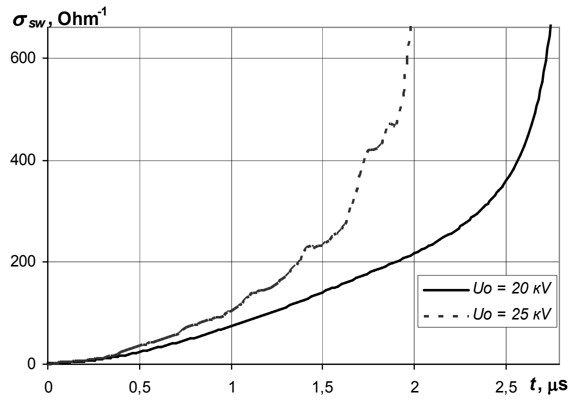
The voltage drop on the switch $U_{sw}(t)$ is described as:

$$U_{sw}(t) = (R_{sw} + dL_{sw}/dt) \cdot I(t) + L_{sw}\, dI/dt = \\ = R_d \cdot I(t) + L_{sw}\, dI/dt = Z_{sw} \cdot I(t) \qquad (2)$$

where R_d – dynamic resistance of the switch.



(a)



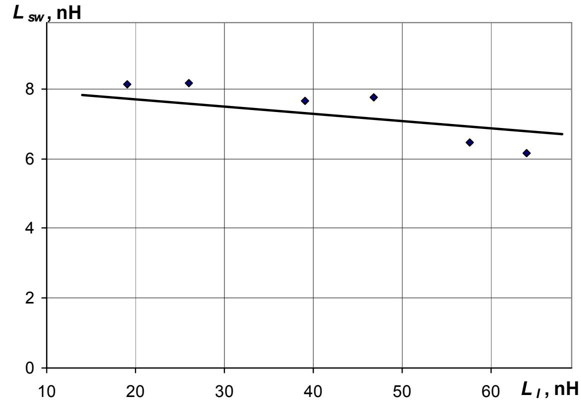
(b)

Fig. 3. Dependences of switch impedance Z_{sw} (a) and switch conductivity σ_{sw} (b) on time at various charging voltage U_o

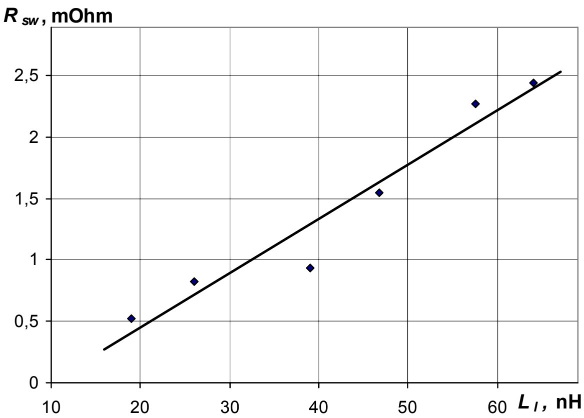
Charging voltage influences on switch impedance changing dynamic $Z_{sw}(t)$ and switch conductivity $\sigma_{sw}(t) = 1/Z_{sw}(t)$ are shown in Fig. 3.

The switch resistance is decreasing when the initial charged voltage increased (see Fig. 3). Similar qualitative dependences for single- and multi-channel trigatron dischargers were obtained in [2]. It is necessary to note, that the first tens nanoseconds switch impedance $Z_{sw}(t) = U_{sw}(t)/I(t)$ is determined with rather big error. It is connected with small value of current. As a result, there is a big influence of noises on measurements at the initial stage of surface discharge evolution.

Dependences of inductance L_{sw} and active resistance R_{sw} of the switch on the load inductance L_l at U_o = 20 kV for time t = 5…18 µs ($t \sim T/3…4/3T$) are given in Fig. 4. For this time (t = 5…18 µs) quasi-stationary stage was detected. At this stage switch inductance and active resistance of switch are constant. Inductance of the switch was defined as $L_{sw} = L_c - L_{con} - L_l$, where L_c – circuit inductance, L_{con} = 8 nH – inductance of the circuit without load (inductances of cables, collector, wireway and capacitor bank). Active resistance of the switch was defined similarly.



(a)



(b)

Fig. 4. Dependences of switch inductance L_{sw} (a) and switch active resistance R_{sw} (b) on load inductance L_l for time t = 5 … 18 µs, U_o = 20 kV

At an initial stage of discharge evolution when there is a formation and expansion of the channels (dL_{sw}/dt has significant value), determining the component R_{sw} from R_d in (2) is difficult. After 4…6 µs up to 18…20 µs $R_d \approx R_{sw}$, inductance of the switch has approximately the constant value and slightly depends on L_l. Increasing U_o up to 25 kV quasi-stationary stages duration of the surface discharge (L_{sw}, $R_{sw} \approx$ const) is increased up to ~30 µs.

4. Conclusions

For optimization of energy input rate and transferring energy efficiency into the load it is necessary to know characteristics of the switch and how they vary with changing capacitor energy and load impedance.

When the initial charging voltage increased, the impedance of the switch is decreased. Such result qualitatively coincides with characteristics of trigatron dischargers. Prominent feature of the surface discharger is the constancy of its electrical characteristics (active resistance and inductance) for time interval $t \sim$ 5…18 µs. For t = 5…18 µs the load inductance shows strong influence on active resistance of the switch; but the load inductance has no effect on switch inductance.

Beside the problem of switch characteristics determining, it is necessary to have the methods of electric energy losses decreasing by means of switch modes selecting at given charging voltage and load impedance. The problem of energy losses decreasing is detailed investigation required.

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