POWERFUL GENERATORS OF HIGH-VOLTAGE PULSES WITH NANOSECOND FRONTS

Purpose. Purpose of the article is to show the possibility of joint efficient operation of semiconductor switches and spark arresters in high-powerful high-voltage generators for obtaining nanosecond and shorter pulse fronts on a high-voltage load. Methodology. The variants of generators of power high-voltage pulses with semiconductor switches in the form of IGBT-transistors, SOS-diodes and spark dischargers as pulse front peaking spark gaps are considered. A scheme is proposed for such a generator of high-voltage pulses with nanosecond front on the basis of a linear pulsed transformer in the Tesla scheme. Results. On the complex load of the generator in the form of a serial connection of a gas bubble in water with a discharge in it and a layer of water under the bubble, voltage pulses with an amplitude of 23 kV and current pulses with an amplitude of 15 A were obtained. In this case, the pulse front, both voltage and current, on the levels 0.1-0.9, was approximately 10 ns, and the repetition rate of pulses in the load ranged from 1200 to 5000 pulses per second. Originality. A scheme is proposed for a generator of high-voltage pulses with a nanosecond front. The difference of the proposed generator with a nanosecond front, high pulse repetition rate, using its high-voltage and low-voltage circuits in the discharge circuit, is the presence in its composition of a linear pulse transformer and a system of peaking of pulse front using SOS diodes and spark gaps. Practical value. These generators considered in this work can find wide application in high-voltage technologies, including decontaminating water treatment, water purification by electric discharges. References 11, figures 3.

Key words: spark gap discharger, generator, switch, transistor, SOS-diode, high-voltage pulse transformer, pulse repetition frequency, capacitive storage, inductance, load resistance.

Introduction. Modern transistor assemblies with operating voltages up to 10 kV and thyristors as power electronic energy switches in low-voltage circuits of pulse generators make it possible to receive microsecond pulses with an amplitude of 25-500 kV on the load connected to the high-voltage terminals of these generators [1, 2]. Generators with semiconductor switches provide a pulse repetition rate of 50,000 pulses per second [3, 4].

In [3-6], generators are presented on the basis of pulse transformers (PT) and IGBT switches in which PT and reverse diodes in IGBT are used to recover energy not released in the load. In this paper, we present modes in which both the high-voltage and low-voltage PT circuits are involved in the discharge circuits of the generators. IGBT-key can be used both as a closing and as an opening switch. In the figures with the diagrams in this article, Lsh, Lsl, is the inductance of the dispersion and the lead-in conductors in the low-voltage and high-voltage winding of the PT respectively. When the IGBT-key is an opening switch and the magnetization inductance is intermediate energy storage, both the high-voltage and low-voltage circuits of PT participate in the discharge circuit of the high-voltage load.

For peaking of the pulse front, SOS diodes in the high-voltage PT circuit, as well as spark gaps, can be used. The purpose of the article is to show the possibility of joint efficient operation of semiconductor switches and spark arresters in high-power high-voltage generators for obtaining nanosecond and shorter pulse fronts on a high-voltage load.

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considering that the total primary winding consists of \( n \) constituent primary windings, each of which includes one MIO 1200-33E10 module with the corresponding driver as IGBT switch, at \( n = 25 \) the commutators of the total primary winding are able to pass the current \( I_{\text{max}} = 30 \, \text{kA} \). And the calculated current \( I_{\text{calc}} \) in the discharge circuit through the total primary winding at \( R_{ld} = 8 \, \text{Ohm} \) is approximately equal to \( I_{\text{calc}} = U_{hv}/R_{ld} \) For \( U_{hv} = 300 \, \text{V} \), \( R_{ld} = 8 \, \text{Ohm} \), \( n = 25 \), \( I_{\text{calc}} = 23.4 \, \text{kA} \). \( I_{\text{max}} > I_{\text{calc}} \) \[8\]. Hence, IGBT-switches can work together with SOS-switches in the discharge circuits of high-power high-voltage generators. Advantages of semiconductor switching systems with IGBT in high-power generators over of switching systems with spark gaps are a higher permissible repetition rate (up to hundreds of thousands of pulses per second), high stability of pulses on the load. In addition, such a switching system provides the ability to control the switching times of IGBT switches on and off and full synchronization of their operation in parallel operation. However, as a final high-voltage switch it is advisable to use a spark gap, since spark dischargers are the most high-speed high-voltage switches that allow obtaining the minimum (subnanosecond) durations of the high voltage pulse fronts on the load. The permissible frequency of following into a load of high-power high-voltage pulses with a nanosecond front is currently limited, probably, by spark gaps at a level of several thousand pulses per second by using forced cooling of their electrodes. The considered generators can find wide application in high-voltage electrotechnologies, including at disinfecting water treatment, water purification by means of electric discharges \[9-11\].

One of the most promising variants of the scheme of a high-power high-voltage generator operating on the \( R_{ld}L_{hv}C_{id} \) load is shown in Fig. 2. After the SOS-diode is pumped back and the current is switched to the capacitance \( C_{id} \), this capacitance is charged during a time interval (half-cycle) \( T/2 \approx \pi (L_{hv}+L_{ld}) C_{id}^{-1} \), with \( C_{id} \) acts as an intermediate energy store. However, to switch the energy to the load \( R_{id}L_{hv}C_{id} \), the switch SD (spark discharger) should work, preferably closer to the end of the half-period \( T/2 \). Then \( C_{id} \) with an energy close to the maximum is connected to the \( R_{id}L_{hv}C_{id} \) load during the switching time. The shorter the switching time, the shorter the pulse front duration formed on the \( R_{id}L_{hv}C_{id} \) load.

Such a scheme allows one to obtain nanosecond pulses with amplitude of hundreds of kilovolts and more on the load by using a linear pulse transformer as a step-up pulse transformer having one turn in the secondary winding and a high-speed spark gap as the closing switch SD. Such an arrester allows achieving switch times in units of nanoseconds or less.

**Experimental results.** Fig. 3 shows the oscillograms of the current and voltage pulses on the load \( R_{id}L_{hv}C_{id} \). The load of the generator was a serial
The connection of a gas bubble in water with a discharge in it and a layer of water under the bubble, that is, the load was nonlinear. Therefore, in the diagram (Fig. 1, 2), the inductance, capacitance and active resistance of the load are shown by variables (general case). The electrode system of the generator in which this nonlinear load was located was a «high-voltage metal rod – a low-voltage (grounded) metal ring under the rod». The oscillograms were obtained in an experimental setup using a simplified scheme in which there is no branch of \( C'_{hv} \), SOS, and the capacitance \( C'_{ph} \) is connected directly to the ends of the secondary winding of the LPT transformer. It follows from the oscillograms that the voltage and current curves are phase shifted relative to each other, the voltage amplitude on the load is approximately 23 kV and the current amplitude is about 15 A. The voltage and current pulse forms are aperiodic decaying with superimposed oscillations with a period of approximately 20 ns. The half-height duration for the voltage pulse was approximately 120 ns, and for the current pulse, about 60 ns. The duration of the pulse front, both voltage and current, over the levels 0.1-0.9 was approximately 10 ns. The repetition rate of pulses to the load ranged from 1200 to 5000 pulses per second. As a voltage sensor, a capacitive voltage divider was used, and a low-inductive current shunt was used as the current sensor. The recording device was a digital oscilloscope RIGOL DSI102E with a bandwidth of 100 MHz. Therefore, when recording pulses with characteristic times less than 10 ns, errors are possible.

![Fig. 3 Typical oscillograms of voltage pulse (1) and current pulse (2) on the load \( R_{G}-L_{G}-C_{id} \)](image)

The value of the division along the process axis for the voltage oscillogram (curve 1) is 7.65 kV/div, and for the current oscillogram (curve 2), 2.4 A/div.

**Conclusions.** A scheme of a high-voltage pulse generator based on a linear pulse transformer using IGBT-switches in its low-voltage circuits is proposed. In the high-voltage part of the generator it is proposed to use SOS-diodes as switches, and spark-gap dischargers as the final power switches. The advantages of the proposed scheme of a high-power generator with a \( R_{id}-L_{id}-C_{id} \) load are shown: the possibility of obtaining high-voltage pulses with nanosecond and shorter fronts on the load at a repetition rate of up to several thousand pulses per second. These advantages are confirmed experimentally. A typical oscillogram of voltage and current pulses is shown on a nonlinear load in the form of a series connection of a gas bubble in water with a discharge in it and a layer of water under the bubble. The half-height duration for the voltage pulse was approximately 120 ns, and for the current pulse, about 60 ns. The duration of the pulse front, both voltage and current, over the levels 0.1-0.9 was approximately 10 ns.

The generators considered in this work can find wide application in high-voltage technologies, including decontaminating water treatment, water purification by electric discharges.

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N.I. Boyko, Doctor of Technical Science, Professor, National Technical University «Kharkiv Polytechnic Institute», 2, Kyrychova Str., Kharkiv, 61002, Ukraine, phone +380 57 7076245, e-mail: qnaboyg@gmail.com