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A High-Power Diode–Dynistor Generator for Gas-Discharge Technologies

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Abstract—A high-voltage pulse generator is considered that contains an output circuit based on series-connected assemblies of reverse switched-on dynistors and drift step-recovery diodes. It forms voltage pulses with a rise time of 4 ns and an amplitude of 24 kV across a load of 50 Ω . The results of using the generator for creating discharges in atmospheric air are presented. The generator forms discharge-current pulses with an amplitude of 1.7 kA and a rise time of 900 ns at a frequency of 100 Hz and switches an energy of ~ 3 J to the charge channel. The possibility of a significant increase in the switched energy has been shown.

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Pulsed devices in which an electric breakdown of a gas gap is used (lasers, high-energy particle emitters, plasma installations for the synthesis of useful elements and decomposition of harmful chemical compounds, various types of biological equipment, etc.) are well known. In these devices, the gas-filled interelectrode gap is broken down when a high-voltage pulse is applied. After the breakdown, the energy required for a particular plasma technology is deposited in the discharge channel. The performance of the gas-discharge technologies increases with an increase in the volume of nonequilibrium plasma, which is determined by the distance between the electrodes. As the interelectrode distance increases, the breakdown voltage of the gas gap increases. The high efficiency of plasma technologies is achieved by creating a high electric-field strength during the discharge development. This requires a short (nanoseconds) front of the breakdown-initiating high-voltage pulse. Since the resistance of the discharge channel is low after the breakdown of the gas-discharge gap, a large current is required for switching a high electrical power to the discharge. Moreover, the discharge-current duration is usually short and is determined by the characteristic time of flame reactions.

Thus, generators for powering gas-discharge devices must first form a high-voltage pulse with a nanosecond front and then switch a fairly large current into the discharge channel. The operating frequency of such generators is determined by the technical characteristics of the used devices and may reach several kilohertz.

Well-known kilohertz generators [1–3, etc.] of high-power nanosecond high-voltage pulses are based

on drift step-recovery diodes (DSRDs) [4–6, etc.]. These generators use an output circuit that contains a storage capacitor, an inductive energy-storage device, and a current opening switch in the form of a DSRD assembly, which are connected in series. First, a fundamentally short (< 500 ns) forward current pulse is passed through the DSRD assembly, thus creating a sharply inhomogeneous distribution of electron and hole concentrations in the base regions of the diodes and providing charging of the storage capacitor. During the discharge of the storage capacitor, a rapidly increasing reverse current flows through the DSRD assembly, which provides the removal of the accumulated carriers from the diode structures and disabling of the DSRD assembly. At a very short (< 300 ns) duration and an optimal density of this current, the disabling time of the DSRD assembly is several nanoseconds. During the shutdown of the DSRD assembly, the current that flows through the inductive storage is switched to the load. The amplitude of the voltage pulse across the load is determined by the product of the switched current and the load resistance. The amount of the switched energy is determined by the amount of energy stored in the inductive storage device by the time of switching the DSRD assembly off.

Since the energy storage time in the inductive storage is limited by the maximum allowable duration of the reverse current through the DSRD assembly and the rate of this current rise is limited by the self-inductance of the storage unit, a large amount of energy switched to the load can only be provided at a high charging voltage of the storage capacitor. As an example, a generator output energy of ~ 0.1 J was achieved

Fig. 1. The electric circuit of the diode–dynistor generator: (*LVU*) low-voltage unit, (*DU*) demagnetization unit, (*CS*) current sensor, (*CC*) coaxial cable, (*S*) spark gap; (*Q*₁) IRGPS60B120KDP, (*Q*₂) IRGPS60B120KDP (2 in parallel); (*D*₁–*D*₃) 80APF12, (*D*₄) 80APF12 (4 in series); (*RSD*) the structure diameter is 16 mm (2 in series), (*DSRD*) the structure diameter is 16 mm (25 in series); (*L*₁, *L*₂) Epcos ferrite 63 × 38 × 50 mm, 15 turns (*L*₁), 4 turns (*L*₂), (*w_r*) single-turn demagnetization windings; (*Tr*) 2NSR alloy 64 × 40 × 60 mm, *w*₁ = 1, *w*₂ = 15; and (*CC*) RK50 (3 m).

in [3] at a charging voltage of the storage capacitor of ~12 kV.

A higher output energy of the generator with a significantly lower charging voltage of the storage capacitor can be obtained when using the circuit shown in Fig. 1. This circuit contains a DSRD assembly, which forms the front and amplitude of the output voltage pulses, and a unit of dynistors (RSDs) that are switched on in a reverse manner [7–10, etc.], which provides switching the DSRD unit off and switching the energy to the load.

RSDs are four-layer thyristor-type silicon devices. Unlike thyristors, they have no control electrode and are switched by reversing the blocked voltage for a short time. When a small reverse voltage is applied, a control current uniformly distributed over the area flows through the RSD structures, causing the accumulation of initiating carriers. When the initial voltage polarity is restored, these carriers provide the quick switching-on of the RSD, which occurs simultaneously over the entire working area. As a result, the RSDs have very small energy losses upon switching of high-power rapidly increasing current pulses.

The diagram in Fig. 1 contains a step-up transformer *Tr*, a *C*₁, *L*₁ magnetic-compression circuit, and the output circuit that consists of a *C*₂ storage capacitor, the RSD unit, an *L*₂ choke, and a DSRD assembly that are connected in series. A spark gap (*S*), which is connected to the DSRD assembly with a coaxial cable (*CC*), is used as the load. A low-voltage unit (*LVU*) provides the pulse power supply of the magnetic-compression circuit. A demagnetization unit (*DU*) provides the flow of a current of ~3 A through the single-turn windings *w_r* of the *L*₁ and *L*₂ chokes, which brings the cores of the chokes into the operating state.

The *C* and *C*₂ capacitors are initially charged to voltages of 1 and 3.5 kV, respectively. When the *Q*₂ transistor is enabled, the *C* capacitor is rapidly (~900 ns) discharged through the *w*₁ winding of the *Tr* transformer. The current in the secondary winding of *Tr* provides charging of the *C*₁ capacitor to a voltage of ~14 kV. Since the *L*₁ choke has a high inductance in the initial state, the voltage at the *L*₂ choke is low during charging of *C*₁. At the moment when the *C*₁ capacitor charging process terminates, the core of the *L*₁ choke saturates. As a result, the inductance of the *L*₁ choke abruptly decreases and the voltage across the *L*₂ choke abruptly increases. When the voltage across the *L*₂ choke becomes higher than the charging voltage of the *C*₂ capacitor, a current *I*₁ with an amplitude of ~250 A and a duration of ~200 ns forms in the RSD–*C*₂–DSRD circuit (see Fig. 2). This current flows through the RSD unit in the backward direction and through the DSRD unit in the forward direction. As a result, the charge of triggering carriers accumulates in the dynistor structures.

The polarity of the current through the RSD and DSRD units changes after the *L*₂ choke core saturates. Since the inductance of the saturated *L*₂ choke is very low, the discharge current of the *C*₂ capacitor through the RSD unit abruptly rises. As a result, a forward voltage is applied to the RSD unit; it is enabled without a delay and switches a rapidly rising current *I*₂ to the DSRD assembly. This current flows through the DSRD unit in the backward direction and determines its switching-off. At the moment of disabling the DSRD assembly, the current *I*₂ (~500 A) is switched to the coaxial cable *CC* with a characteristic impedance of 50 Ω. As a result, a voltage pulse with an amplitude

Fig. 2. The waveforms of the voltage at the C_1 capacitor (U_{C_1}) and the current through the RSD- C_2 -DSRD circuit (I_1 , I_2 , I_3). The vertical scales are 500 A/division (current) and 5 kV/division (voltage); the horizontal scale is 200 ns/division.

of ~ 24 kV and a rise time of ~ 4 ns is formed at the cable input (see Fig. 3).

At the end of the cable CC , the voltage rises to the moment of a breakdown of the spark gap S , which occurs at a voltage of ~ 38 kV (see Fig. 4).

After the breakdown of the spark gap S , the C_2 capacitor discharges through the interelectrode gap. As a result, a discharge current I_3 forms (see Fig. 2) with an amplitude of 1.7 kA and front of ~ 900 ns. The D_4 diode unit provides a unipolar shape of the discharge current. During the discharge-current flow, the energy that is stored in the C_2 capacitor (~ 3 J) is switched to the spark gap S .

As is seen from the waveforms in Fig. 2, when the RSD unit is enabled, the C_1 capacitor undergoes a charge exchange to an inverse voltage of ~ 6.5 kV. The energy that remains in it returns to the LVU unit and is then efficiently used in the next charging of the C capacitor.

The principle of operation of the LVU unit was described [11]. It is as follows.

In the initial state, the C_0 capacitor is charged to a voltage of ~ 300 V. After the Q_1 and Q_2 transistors are enabled, a linearly increasing discharge current of the C_0 capacitor flows through the L inductor and a current sensor (CS). When the current reaches a preset value, the current sensor CS forms a signal in response to which the Q_1 and Q_2 transistors are disabled. As a result, the energy is switched from the L inductor to the C capacitor. When the Q_2 transistor is enabled, this energy is switched to the C_1 capacitor. After the

Fig. 3. The waveform of the voltage at the cable CC input. The vertical scale is 5 kV/division; the horizontal scale is 4 ns/division.

switching process of the Q_2 transistor is over, it is not disabled until the next C capacitor charging cycle.

The recuperation of the energy that remains in the C_1 capacitor after its charge exchange is performed in the following way. The reverse voltage across the C_1 capacitor determines the current flow through the C - D_3 - Q_2 circuit and the C capacitor charge exchange to the reverse voltage. The C capacitor then undergoes a charge exchange to the voltage of the initial polarity through the CS - D_1 - D_2 - L circuit, and the energy that returned to the LVU unit from the C_1 capacitor is transferred to the L inductor. At the moment when the

Fig. 4. The waveform of the voltage across the spark gap S . The vertical scale is 10 kV/division; the horizontal scale is 4 ns/division.

Fig. 5. The waveform of the voltage across the RSD unit. The vertical scale is 1 kV/division; the horizontal scale is 200 ns/division.

initial voltage polarity is restored at the C capacitor, the current that flows through the L inductor is switched to the D_3 – Q_2 circuit and remains virtually constant until the Q_1 transistor is enabled. When Q_1 is enabled, the D_1 diode is switched off, and the discharge current of the C_0 capacitor flows through the L inductor. When this current increases to a specified value, the Q_1 and Q_2 transistors are disabled and the C capacitor is charged to the operating voltage.

This generator was investigated at a frequency of 100 Hz, which was limited by the power of the C_2 capacitor charging voltage. The spark gap S that was used in the experiments had spherical electrodes and was filled with atmospheric air. The RSD unit consisted of two series-connected dynistors with a diameter of structures of 16 mm and an operating voltage of 2 kV. The DSRD assembly consisted of 25 series-connected diodes with a diameter of structures of 16 mm and an operating voltage of 1 kV.

Figure 5 shows the waveform of the voltage across the RSD unit during the discharge-current flow. It follows from this waveform that in the considered mode, the switching energy losses in the RSD unit are low and allow its use at a frequency higher than 1 kHz. The amplitude of the discharge current can be increased with an increase in the capacitance of the C_2 capacitor.

Since the limiting amplitude of the current through RSD and DSRD is proportional to their working area and the group connection of these devices is quite reliable, a higher level of the pulse and average power of the generators that are built according to the considered scheme can be obtained by increasing the diameters of the dynistor and diode structures and increasing their number.

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