# Study on powering electric filters with unipolar high voltage pulses

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**Abstract.** The article presents the devices of existing power supplies for electrical engineering installations and analyzes their disadvantages. The necessity of developing a method for stabilizing discharge processes in corona discharge electric fields is formulated. The calculation of the transient process in the pause between pulses when powered by unipolar high-voltage pulses with a duty cycle of more than 5 is carried out and the conditions under which the discharge currents are stable are determined. A source with two-way power supply and air cooling has been developed to supply electric filters with unipolar high-voltage pulses. The schematic diagram of the source of periodic voltage pulses, the parameters of the circuit elements, the device of the step-up transformer, the oscillogram of the voltage at the output of the generator and the type of voltage at the output of the source are given.

## 1. Introduction

The electric filter's power supply unit is a critical component of an electric gas cleaning facility. The development of contemporary automatic power supply units, which allowed the operation of electric gas purification facilities to be automated, aided the notable increase in installation efficiency and dependability. The special characteristics of technical processes in industries where electrofilters are utilized have resulted in the development of devices of varied designs.

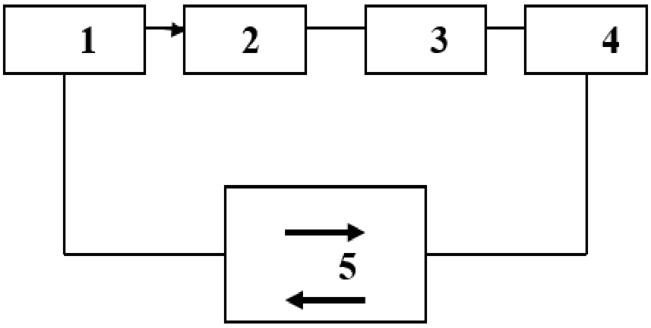

**Fig. 1.** Block diagram of the electrofilter system

Power supplies for electric filters must provide high voltage (several tens of kilovolts and above) at relatively low current consumption (from 10-4 to 10 A). Currently, two types of power supplies are used [1,2]: high-voltage rectifiers; rectifiers with voltage multiplication.

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The electrofilter-power supply unit system (Fig. 1) operates in feedback mode: any change in the active zone of the electrofilter is reflected in the operation mode of the power supply unit. Thus, the efficiency of the electrofilter is largely determined by the method of voltage and current regulation [3]. The use of new automatic control systems and semiconductor rectifiers enabled the development of power supply units with capacities of up to 100 kW, as well as high-performance electric filters for power units with capacities of 300, 500, and 800 MW, powerful cement kilns, blast furnaces, and other high-performance technological units [3].

The peculiarity of the operation of the electrofilter is that it provides the maximum degree of purification at voltages at which spark breakdowns occur in the active zone of the device, which do not turn into arc discharges. The voltage level at which spark breakdowns occur varies over a wide range and depends on a large number of factors: the properties of the exhaust gases, the dust content in the gas, humidity, temperature, size, chemical composition in the electrical conductivity of dust particles, the conditions of formation of the layer on the precipitation electrodes and other factors [3, 4].

Modern power supply units have the following systems for regulating the current and voltage of the electric filter: according to a given current or voltage; according to the power of the corona discharge; according to the level of breakdown voltages; according to the frequency of spark breakdowns; according to the maximum average voltage; according to the voltage of the subsequent field; according to the residual dust content of gases after the electric filter (using a dust meter). The application of the control system is dictated by the physico-chemical properties of the dust and gas flow and, above all, by the magnitude of the specific electrical resistance (resistivity) of dust [11, 4].

The device and schematic diagrams of the power supply units of the first and second generation of APC, AIF and AUF electrofilters are considered in [6]. The ATP series of units includes five modifications that differ from each other in the average values of the rectified current. All units are single-phase. They use silicon bridge rectifiers with symmetrical shielding [4]. Upgraded ATP-type units are produced on the basis of the ATP unit. The SKIF system has been introduced into the units in BULK, which allows automating the regulation of the power supply of electric filters, the operation of the electrode shaking and dust transport system, and the temperature maintenance mode in insulator boxes [3, 4].

## 2. Pulsed and alternating voltages used in gas and electric cleaning procedures

The most common ways to increase the efficiency of electric filters involve the need to reconstruct the electric filter, replace worn-out equipment, which requires large capital expenditures [6]. Using pulse modulation of the power supply is one of the low-cost approaches to boost the efficiency of electric filters in these situations [7].

As of right now, Denmark and Japan, for instance, have expertise operating pulsed microsecond power supplies at huge power units. The Federal State Unitary Enterprise "All-Russian Electrotechnical Institute" conducted extensive research on the development of power supply systems for high-voltage gas purification devices based on electron beam valves and gas discharge devices [9, 10, 11, 12, 13, 14].

Recently, there was no thought to be a broad practical application for the use of alternating and pulse voltages in electric and gas purification processes because of significant technical challenges in designing power supply units that could reliably switch high voltages at a high enough frequency. Powerful high-voltage semiconductor switching devices have recently been developed as a result of advancements in electronics, resolving the technological challenges associated with producing dependable pulsed power supply units. Nevertheless, the literature's knowledge does not offer helpful suggestions for designing industrial devices, and the inconsistent outcomes of experiments and their lack of repeatability raise questions about the practicality of pulsed power supplies. This is because there isn't a strong enough physical model to describe how pulsed power affects dust collection efficiency.

It should be noted that developments were carried out to increase the efficiency of existing electrofilters. Therefore, the issue of reducing weight, dimensions and power consumption was not considered in them. The disadvantages also include the fact that the pulses were generated on the high-voltage side of the sources, which led to a significant increase in their dimensions and a decrease in reliability.

In previous studies, a machine generator was used as a source of periodic pulsed voltages, the basis for voltage generation in which the Lenz principle is based on inducing EMF in a coil when the direction of the magnetic flux changes. The disadvantage of a machine generator is a significant specific gravity per unit of generated power, which is ten times higher than the same type of synchronous generators operating on the principle of electromagnetic induction. Also, a significant disadvantage is the use of a circuit with a step-up transformer and a rectifier with one step of voltage multiplication. When the output voltage of this circuit is up to 20 kV, air cooling was used. At a higher voltage– it is oily.

In terms of cost and operating costs, air-cooled sources are more preferable than oil-cooled ones. Based on the above, it is preferable to use air-cooled sources, and to obtain a voltage of about 40 kV, it is more advisable to use sources with two-way power supply.

## 3. Examination of the transient process during a high voltage source's two-way power supply's interval between voltage pulses

According to the research of Sh.M.Muzafarov [15,16], in order to stabilize the discharge current in the technological discharge gap, it is necessary to fulfill the condition under which the next voltage pulse is supplied under the condition of complete recombination of bulk charges or their number does not interfere with the supply of the next pulse. To obtain unipolar voltage pulses of the order of 40 kV from air-cooled sources, two-way power sources can be used (Fig. 2). Using a step-up transformer T1, the main voltage is raised by producing a constant pulse voltage component. After being rectified by a circuit with voltage multiplication (C1, V1, and V2), the elevated mains voltage is supplied to the discharge gap RP (C2). When the pulsed periodic voltage on the transformer T2 increases, the valve V3 rectifies it and superimposes it on a constant component.

To find the law of change in the circuit's current and discharge gap voltage during the interval between pulses, we will put together the circuit's characteristic equation in complex form using the equivalent circuit (Fig. 3).

$$Z=R_1+R_2+j\omega L+1/j\omega C_2. \tag{1}$$

After substituting p for the multiplier jω, equalize the resultant expression Z(p) to zero:

$$Z(p)=R_1+R_2+pL+1/pC_2, \tag{2}$$

or

$$p^2(C_2L)+pC_2(R_1+R_2)+1=0. \tag{3}$$

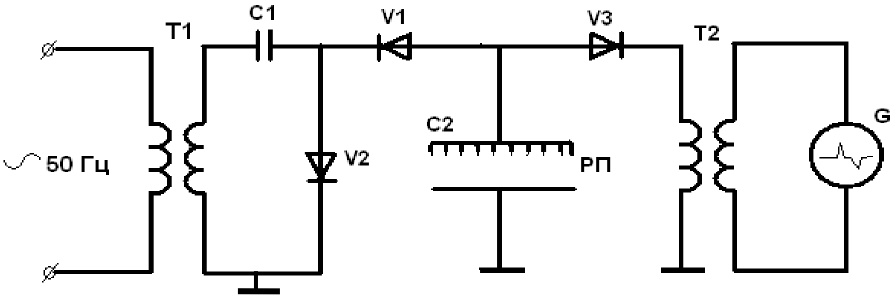


**Fig. 2**. Schematic diagram of generating unipolar high voltage pulses with two-way power supply

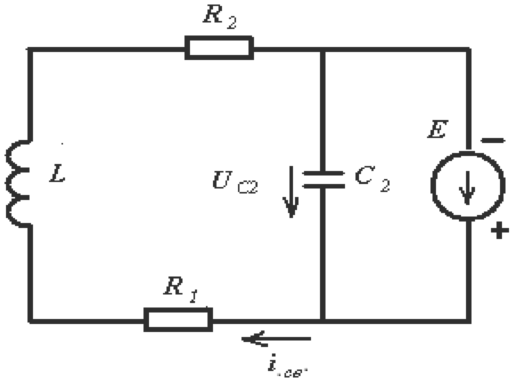


**Fig. 3.** High voltage pulse source replacement circuit with two-way power supply in the pause between pulses

The following equality establishes the roots of the characteristic equation (1):

$$p_{1,2} = \{-C_2(R_1+R_2) \pm[(C_2(R_1+R_2))^2-4(C_2L)]^{0,5}\}/2C_2L). \tag{4}$$

Thus, the discharge gap voltage's free component is as follows:

$$U_{C2} = (A_1e^{p1t} + A_2e^{p2t})+U_0, \tag{5}$$

And power in chain:

$$i_{св} = C_2(A_1p_1e^{p1t}+A_2p_2e^{p2t}). \tag{6}$$

From the initial conditions: $U_{C2,a}=2U_0$ ; $i_{св,0} = i_a$, we will get

$$U_a=A_1+A_2\ ; \quad i_a = A_1p_1 + A_2p_2. \tag{7}$$

From here:

$$A_1 = (p_2A_a - i_a)/(p_2 - p_1), \tag{8}$$

$$A_2 = (p_1A_a - i_a)/(p_2 - p_1). \tag{9}$$

The discharge gap voltage, the circuit current, and the circuit current during the delay between pulses will all fluctuate in accordance with the following law at these values of the integration constants:

$$U_{C2} = \{1/(p_2-p_1)[(p_2U_a-i_a)e^{p1t}-(p_1U_a-i_at)e^{p2t}]+U_0, \quad (10)$$

$$i_{cв} = C_2/(p_2-p_1)[(p_2U_a-i_a)p_1e^{p1t}-(p_1U_a-i_at)p_2e^{p2t}]. \quad (11)$$

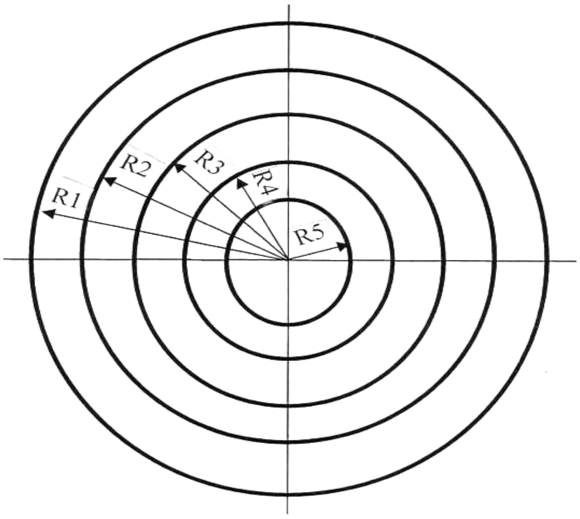


**Fig. 4**. Calculation of the electrical capacity of an electrofilter with three precipitation drums (R1, R3, R5) and two potential drums (R2, R4)

Based on the calculation results, an algorithm was developed for calculating the voltage change of the discharge gap in the pause between pulses (Fig. 4).

We will conduct a comparative analysis of the transient process in the supply chain of the technological discharge gap from a two-way power source for various discharge intervals: 0.1 m and 0.15 m.

For the accuracy of the analysis, we determine the electrical capacity of the electric filters with three precipitation drums, based on the scheme shown in Fig. 4. The following geometric parameters of the electrode system of the electrofilter were used in the calculations: with an interelectrode gap of 0.1 m: R1= 0.5 m, R2=0.4 m, R3=0.3 m, R4= 0.2m, R5= 0.1 m; with an interelectrode gap of 0.15 m: R1= 0.7 m, R2=0.55 m, R3=0.4m, R4=0.25 m, R5=0.1m.

Due to the serial connection of the electrode system of the electrofilter, the capacity was calculated using the formula:

$$C = \frac{2\pi\varepsilon\varepsilon_0\ell}{\ln\dfrac{D_1}{D_2}} + \frac{2\pi\varepsilon\varepsilon_0\ell}{\ln\dfrac{D_2}{D_3}} + \frac{2\pi\varepsilon\varepsilon_0\ell}{\ln\dfrac{D_3}{D_4}} + \frac{2\pi\varepsilon\varepsilon_0\ell}{\ln\dfrac{D_4}{D_5}}$$

$$C = 2\pi\varepsilon\varepsilon_0\ell\left[\left(\ln\frac{D_1}{D_2}\right)^{-1} + \left(\ln\frac{D_2}{D_3}\right)^{-1} + \left(\ln\frac{D_3}{D_4}\right)^{-1} + \left(\ln\frac{D_4}{D_5}\right)^{-1}\right] \quad (12)$$

$$C_{0,,15} = 2\pi\varepsilon\varepsilon_0\ell\left[\left(\ln\frac{D_1}{D_2}\right)^{-1} + \left(\ln\frac{D_2}{D_3}\right)^{-1} + \left(\ln\frac{D_3}{D_4}\right)^{-1} + \left(\ln\frac{D_4}{D_5}\right)^{-1}\right] =$$

$$55{,}578\left[\left(\ln\frac{0{,}7}{0{,}55}\right)^{-1} + \left(\ln\frac{0{,}55}{0{,}4}\right)^{-1} + \left(\ln\frac{0{,}4}{0{,}25}\right)^{-1} + \left(\ln\frac{0{,}25}{0{,}1}\right)^{-1}\right]\bullet 10^{-12} =$$

$$= 55{,}578(4{,}14+3{,}14+1{,}96+1{,}09)10^{-12} = 574{,}12\cdot 10^{-12}\,\Phi \quad (13)$$

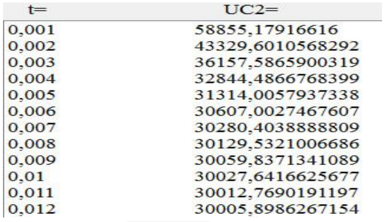
$$C_{0,1} = 2\pi\varepsilon\varepsilon_0\ell\left[\left(\ln\frac{D_1}{D_2}\right)^{-1} + \left(\ln\frac{D_2}{D_3}\right)^{-1} + \left(\ln\frac{D_3}{D_4}\right)^{-1} + \left(\ln\frac{D_4}{D_5}\right)^{-1}\right] =$$

$$55{,}578\left[\left(\ln\frac{0{,}5}{0{,}4}\right)^{-1} + \left(\ln\frac{0{,}4}{0{,}3}\right)^{-1} + \left(\ln\frac{0{,}3}{0{,}2}\right)^{-1} + \left(\ln\frac{0{,}2}{0{,}1}\right)^{-1}\right]\bullet 10^{-12} =$$

$$= 55{,}578(4{,}48+3{,}47+2{,}5+1{,}45)10^{-12} = 661{,}38\cdot 10^{-12}\,\Phi \quad (14)$$

The problem was solved on a computer for two options.

Input parameters of the power supply circuit for the first option H=0.1 m, L=100 Gn; $R_1$=35x$10^3$ Om; $R_2$= 2x$10^6$ Om; C2=661,38$^{-12}$ F; $U_0$=30000; $U_a$=60000 V, $I_a$=0.001 A, $t_0$=0.001 s, $t_k$=0.05s, dt=0.001s and the following results were obtained:



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t=              UC2=
0,001           58855,17916616
0,002           43329,6010568292
0,003           36157,5865900319
0,004           32844,4866768399
0,005           31314,0057937338
0,006           30607,0027467607
0,007           30280,4038888809
0,008           30129,5321006686
0,009           30059,8371341089
0,01            30027,6416625677
0,011           30012,7690191197
0,012           30005,8986267154
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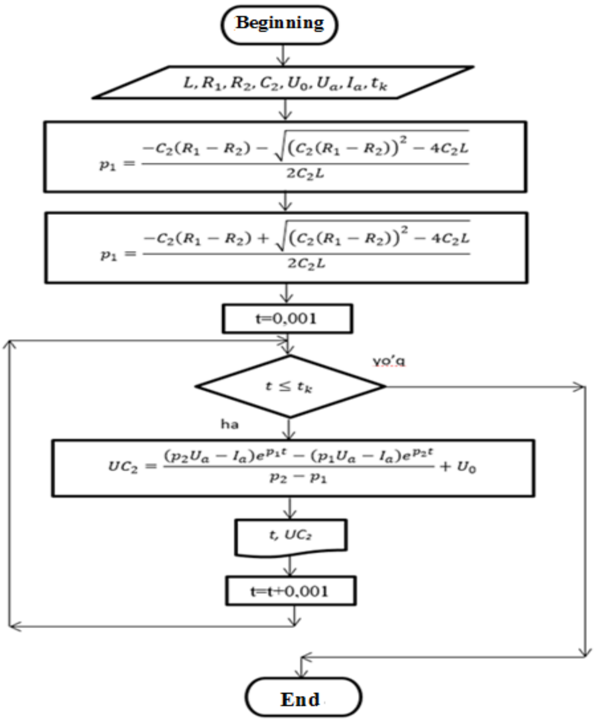

**Fig. 5**. Algorithm for calculating the voltage change of the discharge gap in the pause between pulses

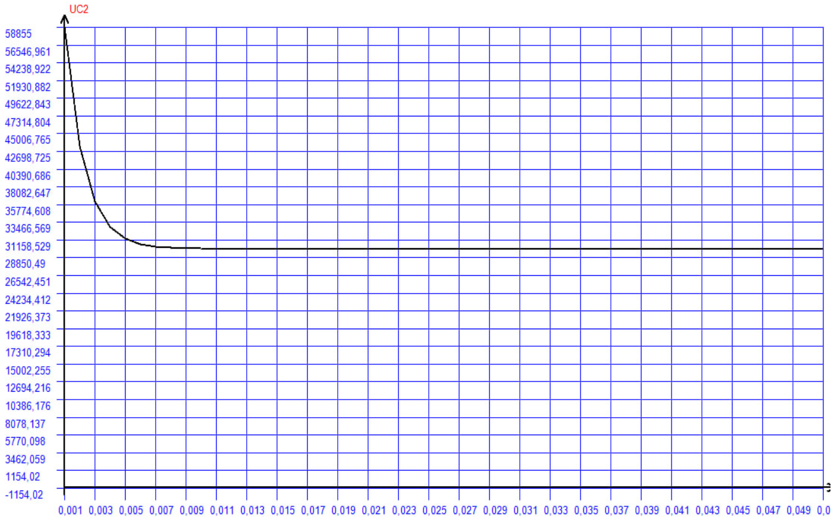

**Fig. 6.** Altering the discharge gap's voltage during the interval between pulses at H = 0.1 m and input parameters of the power supply circuit for the second option: H=0,15 m; L=100 Gn; $R_1$=35x103 Om; $R_2$= 2x$10^6$ Om; $C_2$=574,12$^{-12}$ F; $U_0$=40000; $U_a$=80000 V, $I_a$=0,001 A, $t_0$=0,001 s, $t_k$=0,05s, dt=0,001s.

The maximum frequency that can guarantee a stable process of the corona discharge in the streamer form with the same circuit element parameters should not exceed 140 s-1 for a voltage-multiplying rectification circuit, and 232 s-1 for a circuit with a two-way power supply.

The constant component of the pulse voltage can be changed within the necessary bounds using a two-way power supply circuit. Furthermore, twice the pulse frequency compared to the frequency of periodic voltage pulses is created when a two-half-period rectification circuit is applied. The requirement for two separate high-voltage sources is a drawback of this approach (Figure 7).

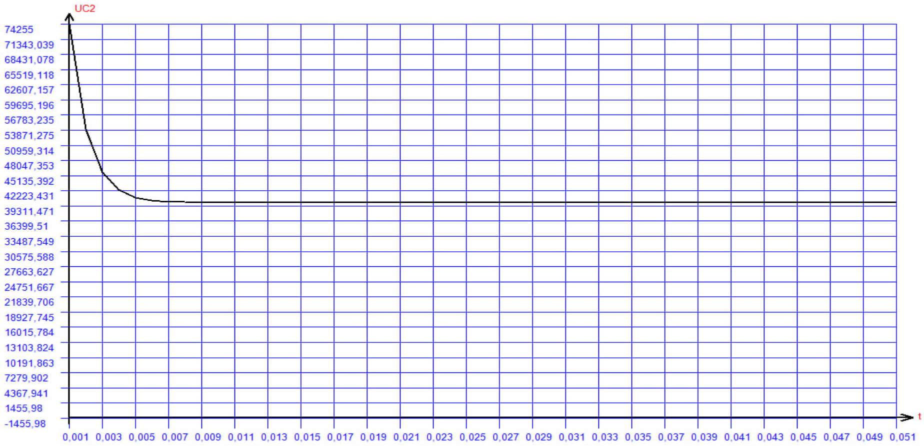

**Fig. 7**. Changes to the discharge gap's voltage during the interval between pulses at H = 0,15 m

A patent of the Agency for Intellectual Property of the Republic of Uzbekistan was obtained for the developed computer calculation program of the transient process in the pause between pulses for a two-way power supply circuit.

## 4. Development and design of a high voltage periodic pulse generator

Experimental studies are necessary to confirm the results of theoretical studies. A high-voltage voltage pulse source with a frequency control range of 100–1000 Hz, a pulse frequency of 5–20, and a maximum voltage pulse amplitude of 30 kV should be used for these investigations. Apart from the above parameters, it is important to offer distinct control over the amplitude of both polarities within the range of (0.5...1) Ua.

A technique was implemented that generates low-voltage periodic voltage pulses that then grow in voltage in order to produce periodic high-voltage voltage pulses. The efficiency of electric and gas purification procedures was improved in [16,17,18] by employing this method of producing unipolar high voltage pulses. As a result of these studies, the deposition zone of aerosol particles was reduced to 0.5...1 m, the flow rate of the purified gas was increased to 8 m/s.

The block diagram of the developed source of high-voltage periodic voltage pulses with two-way power supply (Fig. 8) consists of two parts. The first part, generating unipolar high-voltage pulses, consists of a master generator ZG, a pulse generator FI, an intermediate amplifier UP, a co-ordinator C, a power amplifier UM, a step-up transformer T. The output of the source is connected to an ozone generator GO. ZK, FI and UP are powered by a power supply unit BP 1. The UP is powered by the BP2 power supply unit.

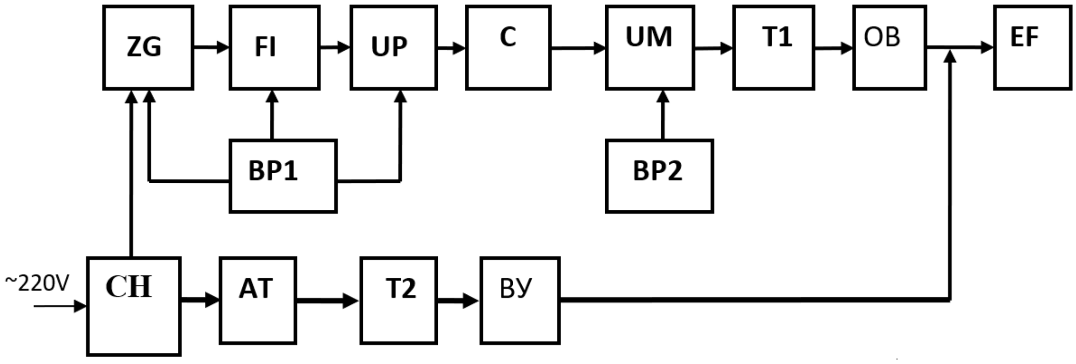

**Fig. 8**. Block diagram of a source of periodic voltage pulses with two-way power supply

The second part, which generates a constant component of the pulse voltage, consists of an autotransformer AT, a step-up transformer T2, a rectifier unit with voltage multiplication. Both parts of the source are powered from an alternating current network with a frequency of 50 Hz through a ferroresonance voltage stabilizer CH.

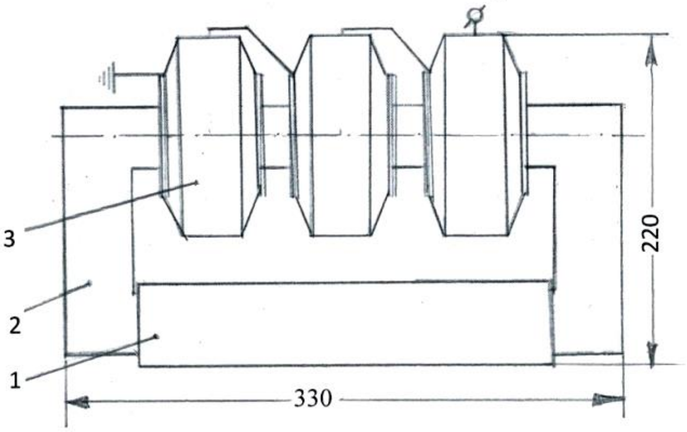

**Fig. 9**. The device of the step–up transformer: 1 -low-voltage winding; 2 – magnetic circuit; 3 – three coils of high-voltage winding

The magnetic circuit of the step–up transformer is made of sheets of electrical steel 0.3 mm thick and is assembled from sheets of 120x40 mm – 270 pieces and 290x40 mm - 270 pieces.

The primary winding is made with a midpoint of a PEV – 2 wire with a diameter of 1.8 mm with a total number of 360 turns. The secondary winding consists of three coils connected in series. It is performed with a PV – 2 wire, 0.15 mm in diameter, with 8000 turns. In coils, interlayer insulation is performed by multilayer paper insulation. After winding, the coils are impregnated with electrical varnish and dried in a thermostat at a temperature of 80 ° C. The input of the first coil is grounded. Its output connects to the input of the second coil. The output of the second coil is connected to the input of the third coil. The terminal of the third coil is a high-voltage terminal.The need to manufacture a secondary winding of a step-up transformer from three separate sections is the need to reduce the parasitic capacitance of the winding, which leads to a decrease in losses in the transformer. Here, a pattern is used in which the total capacitance of series-connected capacitors is less than the smallest capacitance of one of the capacitors.

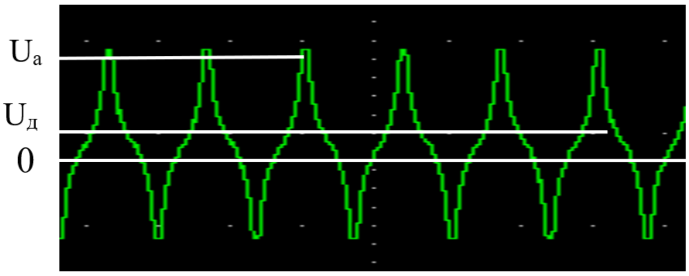

**Fig. 10.** Voltage waveform at the output of the generator of periodic voltage pulses

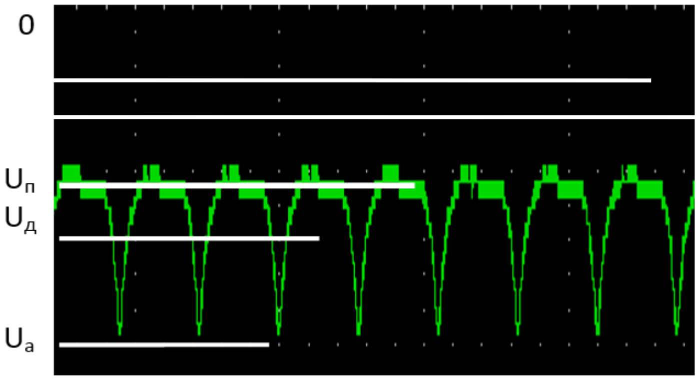

**Fig. 11.**Voltage waveform at the output of a two-way power supply

Fig. 10 shows an oscillogram of the voltage at the output of the generator of periodic voltage pulses indicating the magnitude of the effective voltage Ud, the amplitude of the voltage Ua and the zero value 0.
Fig. 11 shows an oscillogram of the output voltage of a source with two-way power supply and air cooling for powering electrofilters with unipolar high-voltage pulses indicating the value of the constant component Up, the effective voltage Ud, the amplitude of the voltage Ua and the zero value 0.

## 5. Conclusions

a) It is possible to stabilize the discharge process in the electric fields of a corona discharge by combining the actions of independent and non-independent discharges. To stabilize the discharge current in amplitude, it is necessary to ensure full compensation of volumetric charges in the technological discharge gap, or when their concentration will not affect the process of exposure to the next voltage pulse.
b) For a voltage-multiplying rectification circuit, the maximum frequency at which a stable process of the streamer form of the corona discharge is ensured should not exceed 140 s-1, and for a two-way power supply circuit, it should not exceed 232 s-1, using the same circuit element specifications.
c) Within the necessary bounds, the constant component of the pulse voltage can be altered via a two-way power supply circuit. Furthermore, double the pulse frequency in relation to the frequency of periodic voltage pulses is created when a two-half-period rectification circuit is applied. This method's drawback is the requirement for two separate high-voltage sources.

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