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ANALYSIS OF THE CURRENT RIPPLE OF CASCADE GENERATOR HIGH DC VOLTAGE

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Cascade generators - one of the most common sources of high and very high DC voltage. Mostly they are used to power various electrophysical equipment, especially for high-accelerators of various types. Cascade generator is usually from 4-10 stages. Special scheme include using rectifiers and capacitors provide a voltage increase in each stage (compared to previous) on the value of twice the amplitude of the high-voltage transformer connected to the first stage.

Cascade generators are widely used for high voltage, high voltage equipment for testing, as well as for accelerating for ions with energies up to 3.4 MeV and above [12].

First cascade generator was built in 1932 J. Cockcroft and E. Walton, who with the help of ions accelerated to high energies [12].

Also constant high voltage is obtained through a variety of schemes straightening alternating voltage, the main elements of which are high-voltage transformer, capacitor-diode group filter higher harmonics and limiting current resistors [11].

Recently, the High cascading generators are used in technology processing, food processing, industrial electrostatic coal power plants for environmental cleaning waste, etc. [3-5, 8-10].

A characteristic feature is the presence of cascade generators ripple voltage at the output settings. In a study of a number of publications and forms depending on the amplitude of ripple voltage [1, 6], but in such installations also present ripple current that affect their performance not previously been investigated. Therefore, the analysis of their impact for high cascade installations is important.

The purpose of research - analysis of the high ripple current constant voltage cascade generator and study its impact on the characteristics of such facilities.

Materials and methods of research. Analysis of ripple current in the work carried out using the analytical method developed by the authors study the high DC voltage cascade generator [2].

Functional diagram of doubling power installation of high voltage direct current type for generalized [2] shown in Fig. 1. From the output of the high-voltage step-up transformer TR u1 (t) = Um · sin (ω · t) through decoupling capacitor C1 to the input voltage doubling cascade VD1; VD2; C2, and then through the filter Rf; C3 - the component diodes ST1 ... STn with the source resistor r, which included parallel ohmic voltage divider, the load which can be substituted resistant RPN (RPN resistance can also simulates different load generator). Insertion in diodes circuit installation (see. Figure 1) due to the need to reduce ripple and, on the other hand, increasing the accuracy of measurement of high voltage. In addition to the installation scheme [7] in Figure 1 scheme introduced load R2, R3.

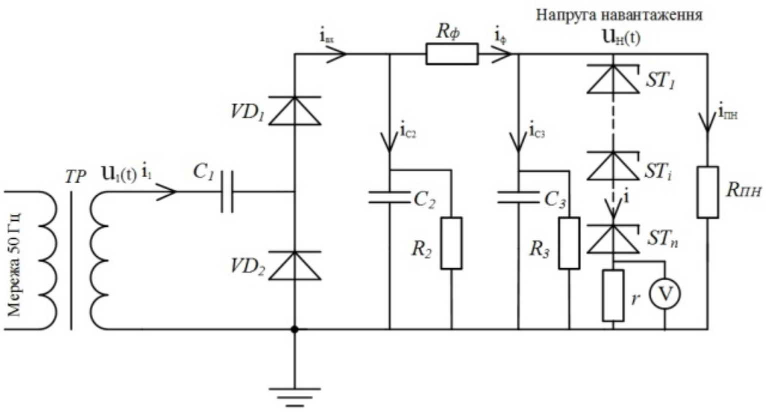

Fig. 1. Functional diagram of high voltage power installations generalized type

Current-voltage characteristics (as an example, zener D818D [7]) shown in Fig. 2. It linearized expression is written as: ust (i) = u0 + rb · (i - I0), where Rd - differential resistance zener.

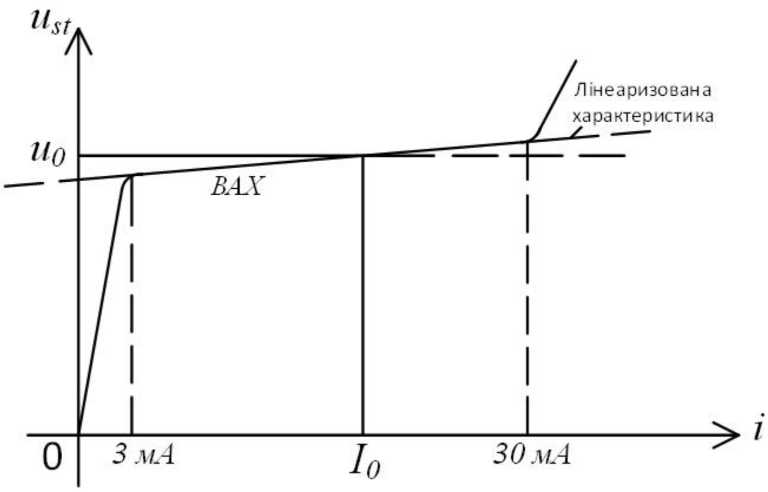

Fig. 2. Current-voltage characteristics of zener D818D

Then for load voltage (see. Fig. 1) can be written: Un = (U0 + I0r) + (i- - I0) (Rd + r), where U0 - equivalent to the voltage and Rd - equivalent differential resistance level diodes.

Allocating Un (t) ripple voltage Δu (t) = Un (t) -U0-I0 · r and conducting transformation [2] first obtained system of equations that describes the process in a scheme of generalized cascade generator type.

In the interval 0 ≤ t ≤ T, where T - period of voltage T = 2π / ω, at time t1 begins charging (recharge) capacitor C2, which ends at time t2, (t2> t1) after which the rice scheme. 1 is a redistribution of stresses within the time T-Δt, where Δt = t2 - t1.

The system of equations describing periodic process established in the scheme of Fig. 1 is [2]:

$$t_1 = \frac{\arcsin\left(\frac{1}{U_m} X_1 - 1\right)}{\omega}, \qquad (1)$$

where

$$X_1 = I_0 R_ф + (U_0 + I_0 r)\cdot\left(1 + \frac{R_ф}{R_3} + \frac{R_ф}{R_{ПН}}\right) + \left(\Delta U_{усталене} + A_3 \sin\psi + A_4 + A_5\right)$$

$$\times\left(1 + \frac{R_ф}{R_{ПН}} + \frac{R_ф}{R_3} + \frac{R_ф}{R_д + r}\right) + C_3 R_ф\left(\omega A_3 \cos\psi + p_3 A_4 + p_4 A_5\right);$$

$$t_2 = \frac{\arccos\left(\frac{X_2}{U_m \omega}\right)}{\omega}, \tag{2}$$

where

$$X_2 = C_3 R_ф \cdot\left[-\omega^2 A_3 \sin(\omega\Delta t + \psi) + p_3{}^2 A_4 e^{p_3 \Delta t} + p_4{}^2 A_5 e^{p_4 \Delta t}\right] +$$

$$+\left(1 + \frac{R_ф}{R_{ПН}} + \frac{R_ф}{R_3} + \frac{R_ф}{R_д + r}\right)\left[\omega A_3 \cos(\omega\Delta t + \psi) + p_3 A_4 e^{p_3 \Delta t} + p_4 A_5 e^{p_4 \Delta t}\right];$$

$$\Delta u_{усталене} = -\frac{(U_0 + I_0 r)\cdot\left[\frac{1}{R_2} + \frac{R_ф}{R_2 R_3} + \frac{R_ф}{R_2 R_{ПН}} + \frac{1}{R_3} + \frac{1}{R_{ПН}}\right] + I_0\left(1 + \frac{R_ф}{R_2}\right)}{\frac{1}{R_2} + \frac{R_ф}{R_2 R_3} + \frac{R_ф}{R_2 R_{ПН}} + \frac{1}{R_3} + \frac{1}{R_{ПН}} + \frac{1}{R_д + r}\cdot\left(1 + \frac{R_ф}{R_2}\right)}. \tag{3}$$

In the charging period t1 ≤ t ≤ t2 Δu (t) has the form

$$\Delta u_з(t) = A_3 \sin(\omega(t - t_1) + \psi) + A_4 e^{p_3\cdot(t - t_1)} + A_5 e^{p_4\cdot(t - t_1)} + \Delta u_{усталене}, \tag{4}$$

and during the redistribution of stress at $t \geq t_2$

$$\Delta u_{ПН}(t) = A_1 e^{p_1\cdot(t - t_2)} + A_2 e^{p_2\cdot(t - t_2)} + \Delta u_{усталене}, \tag{5}$$

$$A_3 = \frac{C_1 \omega U_m}{R_ф C_3 (C_1 + C_2)}\cdot\left[b_1{}^2 \omega^2 + \left(b_2 - \omega^2\right)^2\right]^{-1/2},$$

$\psi = arctg\frac{b_2 - \omega^2}{b_1 \cdot \omega}$, where the coefficients b1; b2; p1; p2; p3; p4 determined by calculation of the characteristic equation [2] and U_m; A_1; A_2; A_4; A_5 decision determined system of equations:

$$A_3 \omega \cos(\omega\Delta t + \psi) + p_3 A_4 e^{p_3\cdot\Delta t} + p_4 A_5 e^{p_4\cdot\Delta t} = p_1 A_1 + p_2 A_2, \tag{6}$$

$$A_3 \omega \cos\psi + p_3 A_4 + p_4 A_5 = p_1 A_1 e^{p_1[T - \Delta t]} + p_2 A_2 e^{p_2[T - \Delta t]}, \tag{7}$$

$$A_3 \sin\psi + A_4 + A_5 = A_1 e^{p_1[T - \Delta t]} + A_2 e^{p_2[T - \Delta t]}, \tag{8}$$

$$A_3 \sin(\omega\Delta t+\psi)+A_4 e^{p_3\Delta t}+A_5 e^{p_4\Delta t}=A_1+A_2, \quad (9)$$

$$\frac{C_1\cdot U_m}{R_\phi\cdot C_3\cdot(C_1+C_2)}\cdot\left[b_1{}^2\cdot\omega^2+\left(b_2-\omega^2\right)^2\right]^{-1/2}\times$$
$$[\cos\psi-\cos(\omega\cdot\Delta t+\psi)]=-\frac{A_4}{p_3}\cdot\left(e^{p_3\cdot\Delta t}-1\right)- \quad (10)$$
$$-\frac{A_5}{p_4}\cdot\left(e^{p_4\cdot\Delta t}-1\right)-\frac{A_1}{p_1}\cdot\left(e^{p_1\cdot(T-\Delta t)}-1\right)-$$
$$-\frac{A_2}{p_2}\cdot\left(e^{p_2\cdot(T-\Delta t)}-1\right)-\Delta u_{усталене}\cdot T.$$

In general, we obtain a system of seven equations that includes seven unknowns: Um; A1; A2; A4; A5; t1; t2. This system has one solution in the set of real numbers for the terms of nominal mode, the parameters of which are defined in [2].

The unique construction solution of equations and high-voltage cascade generator generalized type [2] is that for them to search his regime goes into reverse - not from the primary source voltage, and the final result of his work - the parameters U0, I0 considering values parameters of the circuit, with the desired value of the primary voltage Um is at the end of calculation. This allows you to "synthesize" cascade generator modes depending on the desired outcome and the conditions of his work.

Results. Calculation power supply design installation of high voltage direct current.

Shown in Fig. 1 functional diagram of the power generator of high voltage direct current has parameters that actually meet the state standard installation of high voltage DETU 08.04.99 modes nominal voltage from 1 kV to 180 [7].

Fig. 1 marked:

C1 - decoupling capacitor (0.1 uF);

C2, C3 - battery and filter capacitors (.072 uF);

Rf - resistance filter (1.78 MW);

VD1, VD2 - high voltage diodes;

ST1 ... STi ... STn - D818D zener type;

Mon - ohmic voltage divider (in general - resistance, simulating the load generator).

Zener D818D determine the choice stabilized current settings I.0 = 5 mA to 27 nominal values of input voltage at the load, according to Table. 1. PN voltage divider has four input values Uvh.nom.PN Rated voltage: 180 kV; 90 kV; 60 kV; 30 kV, for which the calculated current voltage divider equal IPN = 2.5 mA. 23 For other input voltages voltage divider current decreases in proportion to its input voltage.

In [7] coefficient of amplitude ripple voltage is determined by the software when replacing diodes Multisim equivalent resistors. In this paper, similar calculations were conducted by the decision obtained equations (1, 2, 6-10) analytical method for the setting in which determined appropriate for each mode. According to the results of analytical calculation in this work as determined amplitude coefficient ripple voltage circuits for high-voltage source (see. Fig. 1). Comparing among themselves the results of analytical calculation and results [7] obtained from Multisim, we note that they are actually the same. In the Table. 1 shows the results of calculations factor amplitude ripple voltage and ripple current amplitude factor analytical method to link diodes (Fig. 1) (the replacement of equivalent resistors) in the case of R2 → ∞, R3 → ∞ (which corresponds to nominal mode setup), on formulas

$\Delta_{\Pi(н)} = \frac{(\Delta u_1 - \Delta u_2)}{2 \cdot U_0} 100\%$, $\Delta_{\Pi(cm)} = \frac{(\Delta_{cm1} - \Delta_{cm2})}{2 \cdot I_0} 100\%$, where Δu_1, Δu_2, Δ_{cm1}, Δ_{cm2} – respectively positive and negative maximum amplitude ripple voltage and current.

1. The estimated value of the voltage Um, ripple voltage amplitude coefficient ΔP (n) and coefficient of amplitude ripple current ΔP (st) for 27 modes of supply units (the replacement of diodes resistors)

$\overline{U}_н$, B	U_m, B	$\Delta_{п(н)}$, %	$\Delta_{п(ст)}$, %	$\overline{U}_н$, B	U_m, B	$\Delta_{п(н)}$, %	$\Delta_{п(ст)}$, %
1000	5939,39	1,244	1,244	60000	40995,59	0,0333	0,0333
2000	6577,69	0,6463	0,6463	70000	45920,41	0,0265	0,0265
3000	7216,07	0,4432	0,4432	80000	51725,99	0,0241	0,0241
4000	7854,52	0,34	0,34	90000	57531,71	0,0223	0,0223

5000	8493,02	0,2775	0,2775	100000	61871,51	0,0171	0,0171
6000	9131,58	0,2357	0,2357	110000	67531,04	0,0159	0,0159
7000	9770,18	0,2057	0,2057	120000	73190,65	0,0149	0,0149
8000	10408,83	0,1832	0,1832	130000	78850,32	0,0141	0,0141
9000	11047,51	0,1656	0,1656	140000	84510,03	0,0133	0,0133
10000	11686,23	0,1515	0,1515	150000	90169,78	0,0127	0,0127
20000	18074,87	0,0875	0,0875	160000	95829.55	0,0121	0,0121
30000	24465,06	0,066	0,066	170000	101489,36	0,0116	0,0116
40000	29092,73	0,0443	0,0443	180000	107149,18	0,0112	0,0112
50000	35044,03	0,0377	0,0377				

They also performed calculations for solution of equations for the values of the parameters r = 10 ohms for modes = 1 ... 10 kV and r = 60 ohms for modes = 20 ... 180 kV. The value determined in accordance with rb [2] of 22 ohms for each zener, and Rd = nrd where n - number of diodes corresponding to each mode, which is determined based on the average value of voltage stabilization D818D u0 = 9 V. The calculations determined factor voltage ripple amplitude ΔP (n) and amplitude ripple current ratio ΔP (c) to link diodes circuit (Fig. 1) that are listed in the Table. 2.

2.The estimated value of the voltage Um, ripple voltage amplitude coefficient ΔP (n) and coefficient of amplitude ripple current ΔP (st) for 27 modes of power installations within the parameters of diodes

$\overline{U}_н$, В	U_m, В	$\Delta_{п(н)}$,%	$\Delta_{п(ст)}$,%	$\overline{U}_н$, В	U_m, В	$\Delta_{п(н)}$,%	$\Delta_{п(ст)}$,%
1000	5971,38	0,3814	6,121	60000	41174,21	0,0323	1,873
2000	6609,63	0,2175	5,95	70000	46094,53	0,0257	1,56
3000	7248,03	0,1692	5,852	80000	51900,12	0,0235	1,472
4000	7886,47	0,1442	5,831	90000	57705,85	0,0217	1,398
5000	8524,96	0,1285	5,781	100000	62041,26	0,0167	1,098
6000	9163,51	0,1174	5,71	110000	67700,81	0,0156	1,042
7000	9802,11	0,1089	5,623	120000	73360,42	0,0146	0,993
8000	10440,75	0,1021	5,525	130000	79020,09	0,0138	0,951
9000	11079,43	0,0963	5,419	140000	84679,8	0,0131	0,913
10000	11718,15	0,0915	5,308	150000	90339,55	0,0125	0,88

20000	18266,51	0,0802	2,944	160000	95999,33	0,0120	0,849
30000	24656,73	0,0621	2,793	170000	101659,13	0,0115	0,822
40000	29271,22	0,0422	2,141	180000	107318,96	0,0111	0,798
50000	35222,53	0,0363	1,992				

The calculation results tables 1 and 2 as relevant dependency ratios amplitude ripple in Fig. 3.

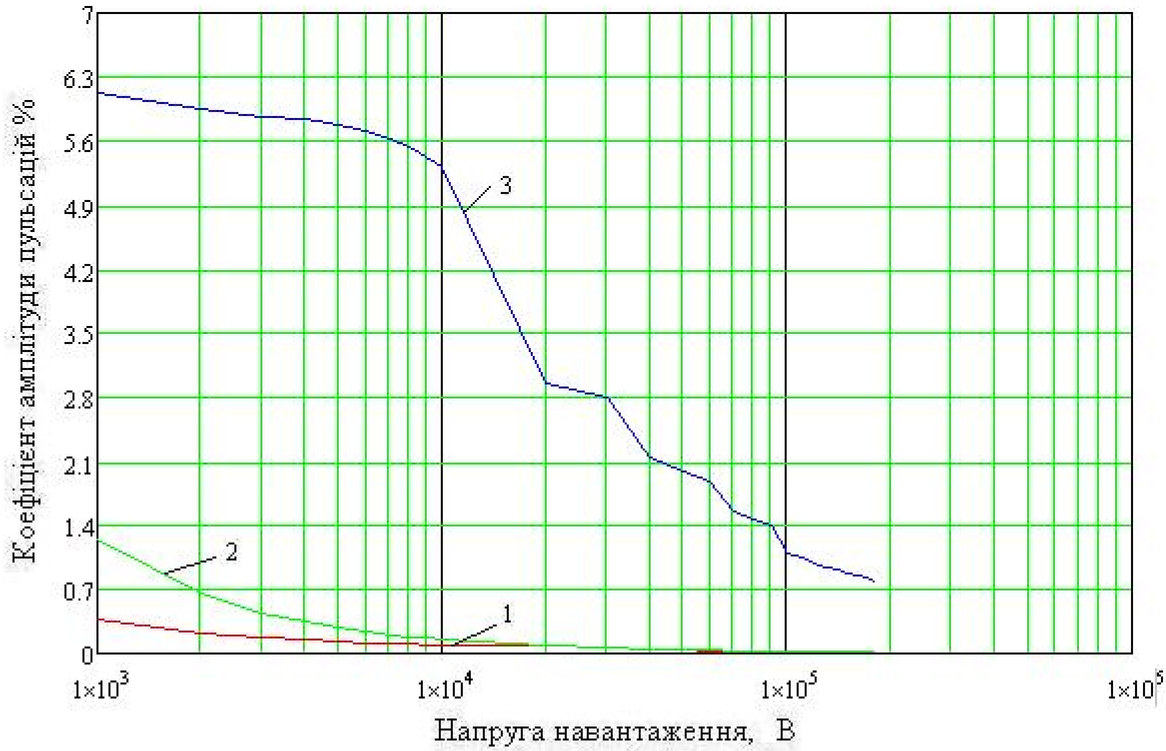

Fig. 3. Dependence of the amplitude ripple current and voltage from load voltage in the range of 1-180 kV:

1 - the coefficient of amplitude ripple voltage derived from the parameters diodes; 2 - factor amplitude ripple voltage and current for diodes, resulting in their replacement resistors; 3 - factor amplitude ripple current diodes

Dependencies are presented in Figure 3 show that the ripple current in the installation of non-linear load is maximum diodes (current ripple, curve 3, in 16-72 times higher than the voltage ripple, curve 1).

However, in case of replacement diodes resistors, ripple voltage (or current) higher than the corresponding ripple voltage of 3.26 times (at = 1 kV) and 1.01 times (at = 180 kV), see. curves 1 and 2 in Fig. 3.

Therefore, the load circuit cascade generator high voltage zener diode, can significantly reduce the ripple voltage amplitude while a sharp increase in amplitude ripple current.

Conclutions

1. The results show that proposed earlier by the authors [2] The analytical method allows highly accurate calculation mode voltage and high-current cascade generators with nonlinear load, determining their quality characteristics as the power source of relevant technological installations.

2. In applying the proposed analytical method designed high power settings cascade constant voltage generator with a nonlinear load. In nominal operating voltage installation mode 1 kV amplitude ripple current is actually 6% (according to calculations carried - 6.121%) and in the mode of 180 kW - 0.798%. Ripple current ratio ΔP (c) significantly differ depending on the installation of high voltage and load.

3. At a certain change of the active elements of the power scheme settings high voltage DC and in giving its nonlinear circuit elements can specifically regulate amplitude ripple coefficient of output voltage (or current).