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EXPERIMENTAL INVESTIGATIONS OF ELECTRO-THERMAL RESISTIBILITY OF CONDUCTORS AND CABLES TO ACTION OF RATIONED ON THE INTERNATIONAL STANDARD IEC 62305-1-2010 APERIODIC IMPULSE OF CURRENT OF ARTIFICIAL LIGHTNING

Purpose. Experimental researches of electro-thermal resistibility of cable-explorer products, applied in the power electric circuits of objects of electric-power industry, to action on its copper and aluminum parts bearings a current rationed on the International Standard of IEC 62305-1-2010 aperiodic impulse 10/350 μs of current of artificial lightning. Methodology. Electrophysics bases of technique of high tensions and high pulsed currents (HPC), and also scientific and technical bases of planning of devices of high-voltage impulsive technique and measuring HPC in them. Results. Experimental a way the quantitative levels of maximal values maximum of possible and critical closenesses of aperiodic impulse 10/350 μs of current of artificial lightning with rationed on the international standard of IEC 62305-1-2010 peak-temporal parameters and admittances on them in copper (aluminum) parts bearings a current of send-offs and cables with a polyethylene (PET) and polyvinylchloride (PVCH) isolation. Originality. First in world practice on the unique powerful high-voltage generator of HPC of artificial lightning experimental researches of resistibility to lightning of pre-production models of send-offs (cables) are conducted with copper (aluminum) tendons, PET and PVCH by an isolation, in-use in power electric circuits of electric-power industry objects. Practical value. The use in practice of protecting from lightning of the got results will allow substantially to promote functional and fire-prevention safety of engineering communications of objects of industrial electroenergy in the conditions of action on them of short shots of linear lightning. References 16, figures 12.

Key words: **high impulsive current of lightning, wires and cables of electric chains of objects of electric-power industry, generator of high pulsed current of artificial lightning, electro-thermal resistibility to lightning of cable-conductor products.**

Приведены результаты экспериментальных исследований электротермической стойкости образцов ряда проводов и кабелей электрических цепей объектов промышленной электроэнергетики с медными (алюминиевыми) жилами (экранами), поливинилхлоридной и полиэтиленовой изоляцией к действию короткого удара большого импульсного тока искусственной молнии с нормированными по международному стандарту IEC 62305-1-2010 амплитудно-временными параметрами и допусками на них. Библ. 16, рис. 13.

Ключевые слова: **большой импульсный ток молнии, провода и кабели электрических цепей объектов электроэнергетики, генератор большого импульсного тока искусственной молнии, электротермическая молниестойкость кабельно-проводниковой продукции.**

Introduction. One of the ways for reliable electrothermal and fire protection from direct (indirect) lightning power facilities (PF) and their utilities is the informed choice of cables and wires installed in their primary and secondary circuits, and complies with strict conditions of lightning resistance. According to the requirements of existing International and national Standards [1-6] with a short lightning in the wire and cable power circuits of the PF can occur pulse currents of positive polarity amplitude I_{mL}, with aperiodic temporary form τ_f/τ_p=10 μs/350 μs, where τ_f, τ_p are, respectively, the acceleration time between the levels (0.1 – 0.9)I_{mL} and duration of the current pulse at the level 0.5I_{mL}. In [1-6], the normalized amplitude-time parameters (ATP) and the tolerances are specified for the aperiodic impulse lightning current corresponding to I-IV levels of protection against lightning of the PF and their utilities. Thus, for example, a lower level IV of the lightning protection of the PF set of ATPs and other characteristics affecting the current pulse are aperiodic 10/350 μs lightning characterized by the following normalized quantitative values [1-7]: τ_p = 350 μs (with a tolerance of ± 10%); I_{mL} = 100 kA (with a tolerance of ± 10%); specific energy (the integral of the action of the lightning current) J_L=2.5·10^6 A^2·s (with a tolerance of ± 35%); fluxed charge q_L=±50 C (with a tolerance of ± 20%). With regard to the numerical value of τ_f, it is, with a tolerance of ± 20% is according to [1-7] and the secondary character may be in the range 10 μs ≤ τ_f ≤ 15 μs. Furthermore, the time t_m≈1,6τ_f, corresponding to a current amplitude I_{mL}, according to the requirements [1-5] must not exceed 25 μs, and by [6] – 50 μs. Currently there are no methodological and other data that can be used to select the specified wire and cable electrical circuits of the PF that meets the existing requirements [1-6]. In this regard the holding of a high-current high-voltage equipment in the experimental studies on the definition of electrothermal lightning resistance of cables and wires of the PF is an actual scientific and technical problem.

Problem definition. Consider widely used in electrical power circuits of the PF wires and cables with copper (aluminum) conductor (screen) in polyvinylchloride (PVC) and polyethylene (PET) insulation. For their electrothermal tests on lightning resistance we use straight test samples (TS) of given wires (cables) with length of 0.5 m, rigidly clamped in a high-current discharge circuit of the generator of the pulsed lightning current (GPLC). As GPLC we select created in 2014 by the Institute «Molniya» of the NTU «KhPI» a powerful high voltage generator ГИТМ-10/350 [7], which reproduces at low impedance and low-inductive electrical load aperiodic current pulses 10/350 μs artificial lightning with positive polarity normalized ATP and tolerance to them, meet the requirements of existing International and national Standards [1-6]. During consideration of experimental studies on the generator ГИТМ-10/350 containing in its structure four concurrent high-voltage pulse current generator (PCG) it is required as a first approximation to determine at room temperature θ_0 = 20 °C maximum limit values δ_{m1d} and critical δ_{m1k} densities of the aperiodic current pulse 10/350 μs of the artificial lightning with normalized ATP [1-6] in the current-carrying parts of mentioned TS of wires and cable of electrical circuits of the PF.

Electrical circuit and parameters of the powerful high-voltage generator ГИТМ-10/350. Fig. 1 shows a circuit diagram of the generator ГИТМ-10/350 used for electrothermal tests on the lightning resistance of the TS of chosen wire and cable of power circuits of the PF.

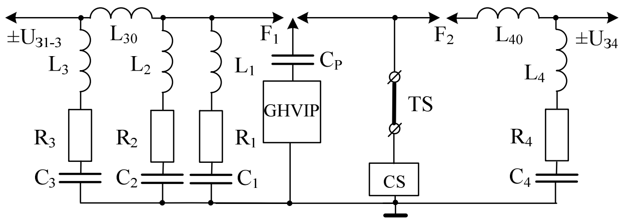

Fig. 1. Circuit diagram of high-current discharge circuits of the generator ГИТМ-10/350 for forming in the TS of wires (cables) of electrical circuits of the PF aperiodic current pulses 10/350 μs of the artificial lightning with normalized ATP and tolerance to them (GHVIP – generator of high-voltage ignitor microsecond pulses of voltage of amplitude up to ± 100 kV; F_1, F_2 – respectively three and two-electrode high-voltage air-spark switches PCG-1 – PCG-4; C_p≈180 pF – blocking capacity for pulse voltage up to ± 120 kV of the GHVIP circuit controlling the actuation of the spark switches F_1 and F_2; TS – test sample of the wire (cable), CS – coaxial shunt type ШК-300 for measuring of pulse current of artificial lightning amplitude from ± 10 A to ± 300 kA; ±$U_{31\text{-}3}$, ±U_{34} – charging voltage, respectively of PCG-1 – PCG-3 and PCG-4; L_1 − L_4, R_1 − R_4 and C_1 − C_4 – respectively intrinsic inductances, resistances and capacitances of discharge circuits of PCG-1 – PCG-4; L_{30}, L_{40} – forming inductances of discharge circuits of PCG-3 and PCG-4) [7]

It can be seen that its four individual PCG (PCG-1 – PCG-4) work in parallel on the total electrical load – tested TS of wires and cables. Note that the PCG-1 – PCG-3 were collected on the basis of 171 parallel included high-voltage pulse capacitor ИК-50-3 (16 for PCG-1, 44 for PCG-2 and 111 for PCG-3), and PCG-4 – on the basis of 288 high-voltage pulse capacitors ИМ2-5-140 consistently included two in each of its 144 connected in parallel sections [7, 8]. Intrinsic electrical parameters of the generator type ГИТМ-10/350 are the following [7]: for PCG-1 − R_1≈0.375 Ω; L_1≈1 μH; C_1≈48 μF; for PCG-2 − R_2≈0.136 Ω; L_2≈1.3 μH; C_2≈132 μF; for PCG-3 − R_3≈0.057 Ω; L_3≈2.5 μH; C_3≈333 μF; for PCG-4 − R_4≈0.083 Ω; L_4≈1.5 μH; C_4≈10.08 μF. Forming inductance L_{30} in the discharge circuit of the PCG-3 is about 40 μH, and forming inductance L_{40} in the discharge circuit of the PCG-4 – about 7 μH.

The nominal value of stored electrical energy in a generator-type ГИТМ-10/350 at a charging voltage for capacitors $U_{31\text{-}3}$ of PCG-1 – PCG-3 at ± 50 kV and a charging voltage for capacitors U_{34} of PCG-4 at ± 5 kV is about 1145 kJ [7]. And, for the PCG-1 – 60 kJ, for PCG-2 – 165 kJ, for PCG-3 – 416 kJ, for PCG-4 – 504 kJ. These data highlight the high levels of energy consumption such as capacitor banks generator ГИТМ-10/350, and point to «hidden» from the reader difficulties for maintenance personnel with such powerful energy storage [9, 10]. To avoid devastating consequences in capacitor banks generator type ГИТМ-10/350 and ensure safe working conditions for maintenance of their personnel in the emergency mode of its work due to electrical breakdown at the stage of the charge (discharge) of the inner or outer insulation of at least one of its 459 capacitors all high-voltage output pulse capacitors in PCG-1 – PCG-4 were installed protective resistance made on the basis of parallel connected high graphite-ceramic volume fixed resistors ТВО-60 with par value of 24 Ω at DC voltage up to ± 25 kV [10, 11]. Parallel operation of PCG-1 – PCG-4 in the mode of the high-current discharge of high-voltage capacitor oscillator type ГИТМ-10/350 on the TS wires (cables) is provided as shown in Fig. 1 simultaneous actuation of the high-voltage three-electrode-managed air switch F_1 with graphite main electrodes having a hemispherical working surface at a nominal voltage of ±50 kV [12] and the high-voltage two-electrode air switch F_2 with graphite rectangular electrodes containing a flat working surface, for a rated voltage of ±10 kV [13]. Synchronous actuation of switches F_1 and F_2 in the presented in Fig. 1 circuit diagram is performed by applying a high voltage across the capacitance C_p dividing by the average graphite spherical electrode F_1 switch from generator of high-voltage ignitor microsecond pulse (GHVIP) of microsecond duration pulse voltage amplitude up to ± 100 kV [7, 10]. When electrical breakdown due to the work of the GHVIP of one of the two air gaps switch F_1 and its subsequent activation occurs surge voltage to the TS of the wire (cable) results simultaneously with F_1 triggered and switch F_2, subsequent discharge to a load (TS) of charged capacitors PCG-1 – PCG-4 and the flow of simulated lightning current pulse with the required ATP through the samples studied wires (cables).

The results of tests of wires and cables for resistance of the PF to current pulse 10/350 μs of the artificial lightning. Fig. 2 is a perspective view of the working table of the generator ГИТМ-10/350 is rigidly fixed to its high-current discharge circuit solid round copper wire diameter of 3.5 mm and a cross-section mm^2 S_1≈9.6 mm^2 of the TS of the RF coaxial cable РК Д2-3,5/9 [14] to the flow by it of the aperiodic current pulse 15/335 μs of the artificial lightning amplitude of about I_{mL}≈85.6 кА.

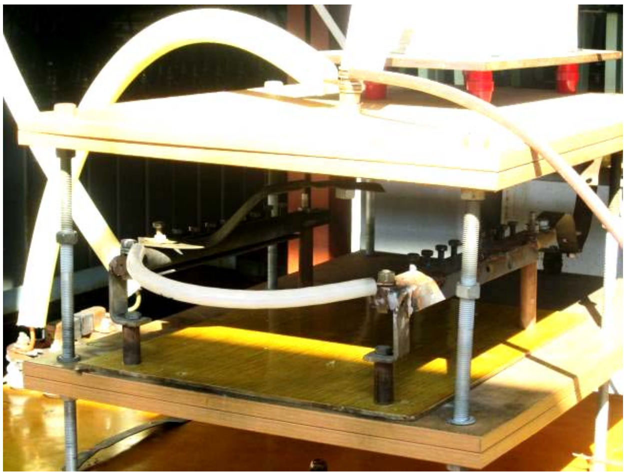

Fig. 2. The view of the workingtable of thepowerful high-voltage generator ГИТМ-10/350 with rigidly fixed to its massive steel electrodes solid round copper wire cross-section of S_1≈9.6 of the TS of the RF coaxial cable РК Д2-3,5/9 with semi-air PET insulation of length of 0.5 m, removed protective sheath and PET twisted copper screen before exposure to the aperiodic current impulse 15/335 μs of the artificial lightning with amplitude I_{mL}≈85.6 кА ($U_{31\text{-}3}$≈16.5 кV; U_{34}≈4.2 кV)

Fig. 3 presents fixed with the help of calibrated by the state metrological service of the measuring shunt type ШК-300 [7, 10] and DSO Tektronix TDS 1012 aperiodic waveform current pulse 15/335 μs of artificial lightning flowing in the discharge circuit of the generator ГИТМ-10/350 via the copper core of the TS of the mentioned cable of the length of 0.5 m. After exposure to the amplitude of the current pulse I_{mL}≈85.6 кА the TS of the RF coaxial cable РК Д2-3,5/9 was visually as a whole and, accordingly, electrodynamically and electrothermally not damaged.

The maximum current density in the copper conductor on the particular cable was about δ_{m1}≈I_{mL}/S_1≈8.9 kA/mm^2. Found in a copper conductor RF cable РК Д2-3,5/9 with PET insulation for the case (I_{mL}≈85.6 кА; J_L≈2·10^6 А^2·s) calculated by taking into account [15] The peak value of the maximum permissible density δm1d current pulse 15/335 μs of the artificial lightning from the ratio δ_{m1d}≈1.353·10^8·$I_{mL}/(J_L)^{1/2}$ is approximately equal to δ_{m1d}≈8.2 кА/mm^2. It is known that at this average density δ_{m1d} pulsed current in a copper conductor of said cable, the maximum permissible short-term temperature heating θ_{1k} it will not exceed 120 °C [15, 16]. From the obtained approximate data that the calculated value of the current density δ_{m1d}≈8.2 кА/mm^2 different from its experimental value δ_{m1d}≈8,9 кА/mm^2 about 8%.

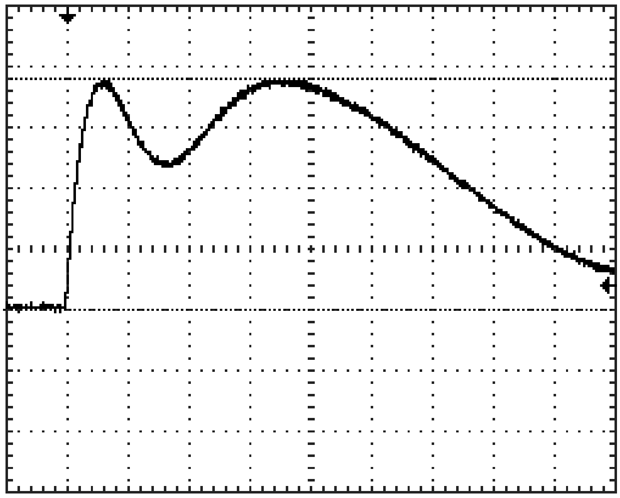

Fig. 3. Oscillogram of the aperiodic artificial lightning current pulse generator circuit type ГИТМ-10/350 in the discharge of its PCG-1 – PCG-4 on the solid round copper conductor of cross-section S_1≈9.6 mm^2 of the RF cable brand РК Д2-3,5/9 with semi-air PET insulation of the length of 0.5 m, and removal of the protective sheath of PET and twisted copper screen (I_{mL}≈85.6 kA; δ_{m1}≈I_{mL}/S_1≈8.9 kA/mm^2; τ_f≈15 μs; t_m≈25 μs; τ_p≈335 μs; J_L≈2·10^6 A^2·s; q_L≈42 C; $U_{31\text{-}3}$≈16.5 kV; U_{34}≈4.2 kV; vertical scale – 22.52 kA / cell; the horizontal scale – 50 ms / cell)

Fig. 4 shows a working table of the generator ГИТМ-10/350 with electrodes attached to his split round copper conductor cross-section of S_1≈3.2 mm^2 of the TS of the RF coaxial cable РК 50-7-11 with solid PET insulation [14] of the length of 0.5 m before exposure to the current pulse of 15/335 μs of the artificial lightning amplitude up I_{mL}≈85.6 кА.

Fig. 5 shows the initial stage of the electrical explosion (EE) of the copper conductor of the cross-section of S_1≈3.2 mm^2 tested in the discharge circuit of the generator type ГИТМ-10/350 of the TS of the RF coaxial cable РК 50-7-11 with a solid of length of 0.5 m. Filming of the EE of the indicated copper wires made with the help of a digital camera s Canon M307E with its subsequent storyboard. The examination of the investigated TS after its electrothermal test indicates total sublimation of its copper from the interior of PET belt insulation cylindrical configuration of radio frequency coaxial cable РК 50-7-11.

Fig. 4. The view of the working table of the generator ГИТМ-10/350 with rigidly fixed to its massive steel electrodes split round copper conductor with cross-section S_1≈3.2 mm^2 of the TS of the RF coaxial cable РК 50-7-11 with a solid PET insulation of the length of 0.5 m and «plugged» with electrothermal tests its braided copper shield-up exposure to the aperiodic current pulse 15/335 μs of the artificial lightning amplitude of about I_{mL}≈85.6 кА (U_{31-3}≈16.5 кV; U_{34}≈4.2 кV)

Fig. 5. The initial stage of EE of the copper conductor with cross-section of S_1≈3.2 mm^2 of the TS of the RF coaxial cable РК 50-7-11 with a solid PET insulation of the length of 0.5 m in the high-current discharge circuit of the generator ГИТМ-10/350

Fig. 6 shows in enlarged form an end cutting of the TS of the RF coaxial cable РК 50-7-11 with solid PET insulation of length of 0.5 m after exposure to the test current pulse 17/310 μs with amplitude I_{mL}≈82.9 кА according to the oscillogram, shown in Fig. 7 and EE of its split round copper conductor cross-section of S_1≈3.2 mm^2. The average peak value of pulse current density in the exploding electrical copper conductor was in this case δ_{m1}≈I_{mL}/S_1≈25.9 кА/mm^2.

Fig. 6. View of the end cutting of the TS of the RF coaxial cable РК 50-7-11 with a solid PET insulation of the length of 0.5 m after passing on his split round copper conductor of the cross-section of S_1≈3.2 mm^2 of the test current impulse 17/310 μs by the artificial lightning from the generator ГИТМ-10/350 and its EE with complete sublimation of copper (I_{mL}≈82.9 кА; δ_{m1}≈I_{mL}/S_1≈25.9 кА/mm^2; τ_f≈17 μs; t_m≈28 μs; τ_p≈310 μs; J_L≈1.76·10^6 А^2·s; q_L≈37.9 С)

The calculated estimation for this electro-thermal case (I_{mL}≈82.9 кА; J_L≈1.76·10^6 А^2·s) of the maximum value of the critical density of the current pulse 17/310 μs of the artificial lightning ratio δ_{m1k}≈4.416·10^8·I_{mL}/(J_L)$^{1/2}$ [15] indicates that δ_{m1k}≈27,6 кА/mm^2. It can be concluded that for copper conductor cable brand РК 50-7-11 estimated value of the current density δ_{m1k}≈27.6 кА/mm^2 from its experienced values δ_{m1k}≈25.9 кА/mm^2 differs by about 6%.

We note that used in Fig. 3, 6 and 7, the value passed through the current-carrying parts of the TS wires and cables in the discharge circuit of the generator type ГИТМ-10/350 electric charge q_L was determined by the ratio q_L≈$k_L I_{mL}$(1.32τ_p+0.27t_m), where k_L is the normalizing factor for changing our experience in the range (1.092 – 1.112).

Fig. 8 captures the moment of preparation for electrothermal tests in high-current discharge circuit from the generator ГИТМ-10/350 of the TS of the wire ПНП 2×2,5 with PVC insulation of the length of 0.5 m, comprising two parallel connected to the massive steel electrodes desktop used high voltage pulse current solid round copper conductor of the cross-section of S_1≈5 mm^2.

Fig. 9 shows of the wire ПНП 2×2,5 with a PVC insulation, experienced the impact of its two parallel-connected to the discharge circuit of the generator type ГИТМ-10/350 solid round copper conductor of the total section of S_1≈5 mm^2 of the aperiodic current pulse 17/335 μs of the artificial lightning amplitude I_{mL}≈83.8 кА. The average peak value of pulse current density of large veins in the copper wires of the test in this case was equal to about δ_{m1}≈I_{mL}/S_1≈16.8 кА/mm^2.

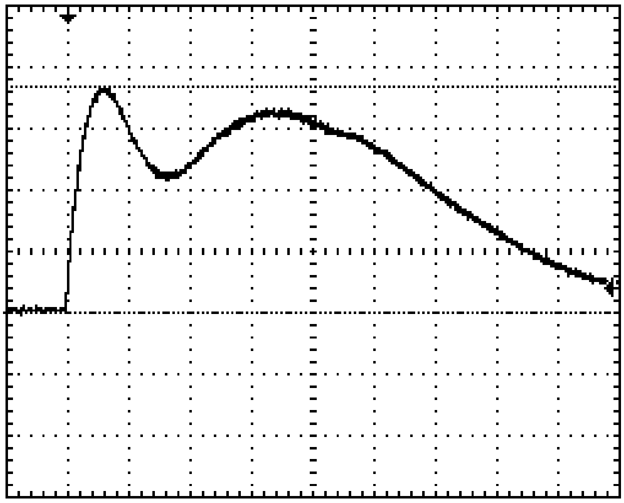

Fig. 7. Oscillogram of the aperiodic artificial lightning current pulse in the circuit of the generator ГИТМ-10/350in the discharge of its PCG-1 – PCG-4 to the electrically exploding digested a round copper conductor of the cross-section of S_1≈3.2 mm^2 of the RF coaxial cable РК 50-7-11 with a solid PET insulation of the length of 0.5 m without the use of tests at its copper-braided screen (I_{mL}≈82.9 кА; δ_{m1}≈I_{mL}/S_1≈ ≈25.9 кА/mm^2; τ_f≈17 μs; t_m≈28 μs; τ_p≈310 μs; J_L≈1.76·10^6 A^2·s; q_L≈37.9 C; $U_{31\text{-}3}$≈16.5 kV; U_{34}≈4.2 kV; vertical scale – 22.52 kA / cell; the horizontal scale – 50 ms / cell)

Fig. 8. View of the working table of the generator ГИТМ-10/350 with rigidly fixed on its massive steel electrodes with solid round copper conductors of the total section of S_1≈5 mm^2 of the TS of the wire ПНП 2×2,5 with a PVC insulation of the length of 0.5 m to the impact on them aperiodic current pulse 15/335 μs of the artificial lightning of amplitude of about I_{mL}≈85.6 кА ($U_{31\text{-}3}$≈16.5 kV; U_{34}≈4.2 kV)

Oscillogram acting on the TS of solid round copper wire conductors ПНП 2×2,5 with PVC insulation by the aperiodic pulse current artificial lightning in this case, virtually the same waveform shown in Fig. 3. Copper wire strands of weathered rendered them strong electro and electrodynamic effects, and its PVC insulation – no. In this case, there has been a local destruction of its PVC insulation because of its heat from flowing through the veins of copper wire considered aperiodic pulse 17/335 μs of the artificial lightning current amplitude I_{mL}≈83.8 кА.

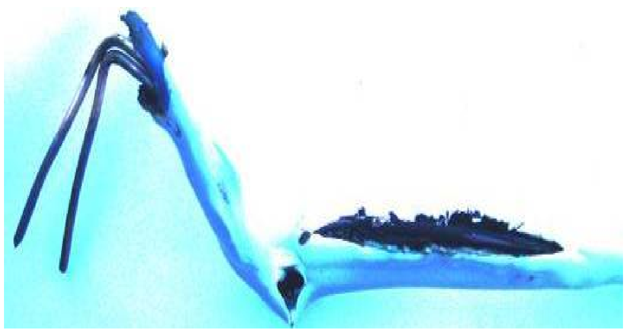

Fig. 9. View of the fragment of the TS of the wire ПНП 2×2,5 with PVC insulation with two parallel-connected in the discharge circuit of the generator ГИТМ-10/350 with round copper conductors of the total section of S_1≈5 mm^2 after flowing over them aperiodic pulse test current 17/335 μs of the artificial line lightning (I_{mL}≈83.8 кА; δ_{m1}≈I_{mL}/S_1≈16.8 кА/mm^2; τ_f≈17 μs; t_m≈28 μs; τ_p≈335 μs; J_L≈1.91·10^6 A^2·s; q_L≈41.2 C; $U_{31\text{-}3}$≈16.5 kV; U_{34}≈4.2 kV)

At considerable heating of the PVC insulation in this type of testing also indicates that the average maximum density pulse current δ_{m1}≈16.8 кА/mm^{2}copper wire ПНП 2×2,5 about 1.8 times the estimated maximum amplitude value allowable density used therein pulse current equal δ_{m1d}≈1.506·10^8·$I_{mL}/(J_L)^{1/2}$≈9.1 кА/mm^2 [15]. In addition, the estimation of the temperature θ_1 of the pulse Joule heating by flowing 17/335 μs pulse current copper wires of said wire on the settlement ratio (2) from [15] shows that she was about θ_1≈912 °C. Of course, what is the value of θ_1 is much higher than the maximum permissible short term temperature θ1k heating wires (cables) with PVC insulation, is about 150 °C [15, 16]. These data indirectly confirm the accuracy of the experiment we found the maximum allowable maximum density of 15/335 μs pulse current linear artificial lightning current carrying parts of copper wires (cables) with PET and PVC insulation, strength totaled about δ_{m1d}≈9 кА/mm^2.

Fig. 10 shows view of electrodes attached to the working table of the generator ГИТМ-10/350 of the TS of the continuous circular aluminum АППВнг2×6 conductor of the cross section S_1≈6 mm^2 of the wire with PVC insulation length of 0.5 m (second aluminum conductor wire was tested by us «muffled»).

Fig. 10. View of the working table of the generator ГИТМ-10/350 with rigidly fixed to its massive steel electrodes solid circular core section of the TS of the continuous circular aluminum АППВнг2×6 conductor of the cross section S_1≈6 mm^2 of the wire with PVC insulation length of 0.5 m before exposure by the aperiodic current pulse 15 / 335 μs of the artificial lightning of amplitude of about I_{mL}≈85.6 кА ($U_{31\text{-}3}$≈16.5 kV; U_{34}≈4.2 kV)

Fig. 11 oscillogram of the test pulse 17/265 μs of the artificial lightning current of amplitude I_{mL}≈83.8 кА flowing through electrically exploding in high-current discharge circuit of the generator ГИТМ-10/350 aluminum conductor with cross-section of S_1≈6 mm^2 of the АППВнг2×6 wire with PVC insulation δ_{m1}≈I_{mL}/S_1≈14 кА/mm^2) is presented.

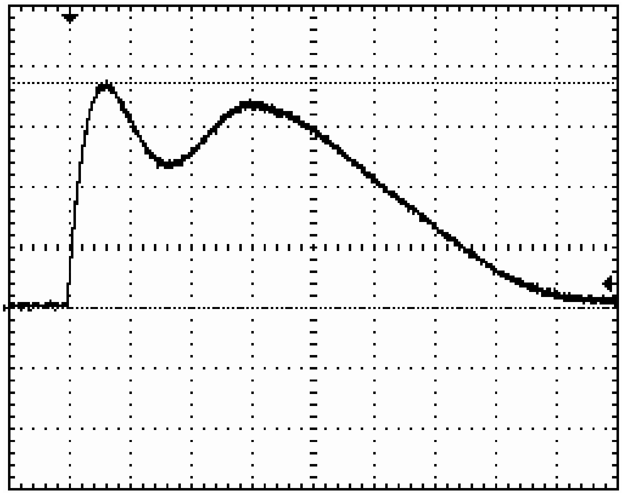

Fig. 11. Oscillogram of the aperiodic artificial lightning current pulse in the circuit of the generator ГИТМ-10/350 at the discharge of its PCG-1 – PCG-4 to electrically exploding solid circular aluminum conductor of the of cross-section S_1≈6 mm^2 of the АППВнг2×6 wire with PVC insulation of the length of 0.5 m (I_{mL}≈83.8 кА; δ_{m1}≈I_{mL}/S_1≈14 кА/mm^2; τ_f≈17 μs; t_m≈28 μs; τ_p≈265 μs; J_L≈1.58·10^6 A^2·s; q_L≈33.3 C; $U_{31\text{-}3}$≈16.5 kV; U_{34}≈4.2 kV; vertical scale – 22.52 kA / cell; the horizontal scale – 50 ms / cell)

Fig. 12 shows an intermediate stage of the EE of the tested in the generator ГИТМ-10/350 discharge circuit [7] of the aluminum cord of the cross-section of S_1≈6 mm^2 of the TS of the wire АППВнг2×6 with PVC insulation of the length of 0.5 m (I_{mL}≈83.8 кА; δ_{m1k}≈14 кА/mm^2).

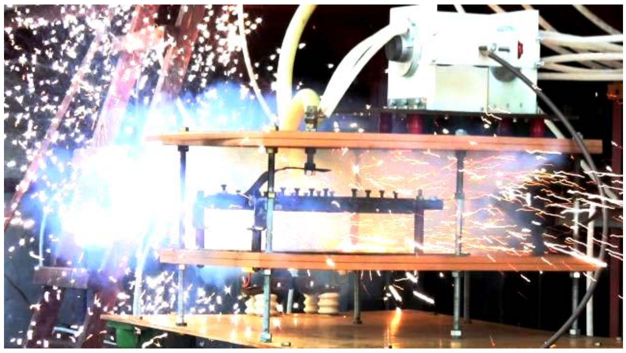

Fig. 12. An intermediate stage of EE of the continuous circular aluminum conductor of the cross-section of S_1≈6 mm^2 of the TS of АППВнг2×6 wire with PVC insulation of the length of 0.5 m in the high discharge circuit of the generator ГИТМ-10/350

The estimated maximum value of the critical density of the current pulse 17/265 μs of the artificial lightning for the aluminum core of the wire АППВнг2×6 with PVC insulation by the approximation ratio δ_{m1k}≈2.863·10^8·I_{mL}/$(J_L)^{1/2}$ [15] indicates that in this electrothermal case it is about 19 kA / mm^2. Obtained empirically for the aluminum core value δ_{m1k}≈14 кА/mm^2 is different from the calculated value δ_{m1k}≈19 кА/mm^2 approximately 26%. Made in further experiments on the generator ГИТМ-10/350 of the TS of АППВнг2×6 wire with PVC insulation length of 0.5 m and its two parallel electrodes are connected to the discharge circuit of said high-current pulse current generator artificial lightning aluminum conductors general section S_1≈12 mm^2 (Fig. 13) showed that the test was carried out at virtually survived have had a strong electro and electrodynamic effects.

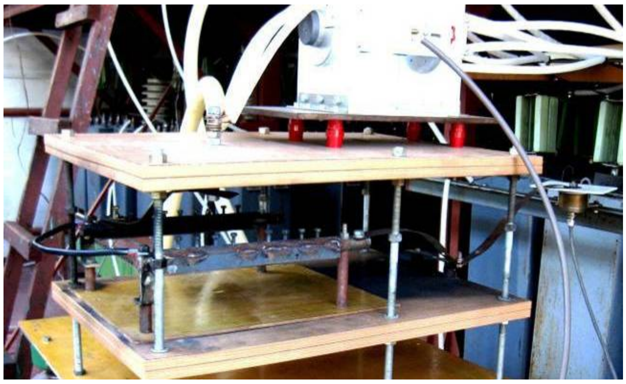

Fig. 13. View of the wire АППВнг2×6 with PVC insulation of the length of 0.5 m with its parallel electrodes connected to working table of the generator ГИТМ-10/350 with two aluminum cords of total section of S_1≈12 mm^2 to exposure by the pulse current 15/335 μs of the artificial lightning of amplitude I_{mL}≈83.8 кА (on the right the measurement shunt ШК-300 [7, 10] included in the high-current discharge circuit of the generator is clearly shown)

Oscillogram of the test pulse 15/335 μs of the simulated lightning current with amplitude I_{mL}≈83.8 кA in this case, virtually the same as the waveform shown earlier in Fig. 3. The peak pulse current density in the mentioned aluminum wire cord of the TS was about $\delta_{m1}≈I_{mL}/S_1$≈6.9 кA/mm^2. Assessment of the maximum allowable limit of the current density in the TS of the aluminum wire of with PVC insulation at 15/335 μs pulse current on the settlement ratio $\delta_{m1d}≈0{,}975·10^8·I_{mL}/(J_L)^{1/2}$ [15] leads us to the fact that in this case δ_{m1d} ≈5.9 кA/mm^2. We can see that obtained with electrothermal tests experienced the peak value of the maximum permissible density δ_{m1d}≈6.9 кA/mm^2 of the used pulse 15/335 μs pulse of current of the artificial lightning in the aluminum cord of the wire АППВнг2×6 with PVC insulation from the corresponding calculated value δ_{m1d} ≈5.9 кA/mm^2 is different by about 14%.

Conclusions.

1. For the first time experimentally it was found that when dealing with actual applications of lightning protection of electrical circuits of industrial electric power to a short stroke of lightning discharges in accordance with the requirements of a number of currently valid international and national standards must be assumed that the maximum allowable pulse density of 15/335 μs lightning current in the current-carrying parts of copper wires (cables) with PET and PVC insulation equals about δ_{m1d}≈9 кA/mm^2, and in the current-carrying parts of their aluminum wires (cables) with PVC insulation – δ_{m1d}≈6 кA/mm^2.

2. From the results experimental studies, carried out in the Institute «Molniya» of the NTU «KhPI» for lightning resistance of samples of cables and wires of the PF on a unique high-voltage current pulse generators of artificial lightning type ГИТМ-10/350 it is follow that the critical density of its impulse 15/335 μs of the current in the copper current-carrying parts of wires (cables) with PET and PVC insulation is about δ_{m1k}≈26 кA/mm^2 and for aluminum current-carrying parts of wires (cables) with PVC insulation – about δ_{m1k}≈14 кA/mm^2 . When reaching in copper (aluminum) cords (screens) of the wires and cables of the electrical circuits of the PF of such a density of the current pulse of lightning they will be subject to EE and failure.

3. Found experimental values of densities δ_{m1d} and δ_{m1k} of normalized according to the requirements of existing International and national Standards of 15/335 μs pulse current artificial lightning in the aluminum and copper live parts of cables and wires of electric circuits of thePF are the appropriate choice and reasonable installation with their view of similar products in electrical power circuits of the PF will help to improve their operational and fire safety in the active thunderstorm activity in a constantly environmental aspects of industrial electric power air atmosphere.

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