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MODERNIZATION OF THE COMPLEX TYPE IK-1U FOR MEASURING THE IMPEDANCE OF THE GROUNDING DEVICE OF A LIGHTNING ARRESTER AND SUPPORTS OF TRANSMISSION LINES

Purpose. The creation of a measuring device for determining the impedance of the grounding of lightning arresters and supports of overhead lines under the influence of aperiodic pulses with the parameters 1.2/50 μs, 8/20 μs and 10/350 μs. Methodology. For this purpose, electrical engineering theory, transient modeling software and natural modeling methods are used. Results. The parameters of the electrical circuits of the additional forming unit were determined to create lightning current pulses with parameters of 10/350 μs using the IK-1U measuring complex. According to the simulation results, a layout of the forming unit in the form of an attachment and the IK-1U complex with the upgraded power supply system were created. Oscillograms of the front and pulse duration are obtained. The specified model was tested when performing electromagnetic diagnostics of the state of the RFP for more than 100 operating electrical substations. Originality. The measuring complex IK-1U was improved, which made it possible to determine the impulse impedance of the grounding device of lightning arresters when exposed to a current of 10/350 μs, 8/20 μs and of voltages 1.2/50 μs. Practical value. Upgraded device allows measurements in accordance with modern international requirements. References 9, tables 1, figures 3.

Key words: **impedance, grounding device, lightning current (voltage) pulse, measuring complex.**

Метою роботи є створення вимірювального приладу для визначення опору заземлювальних пристроїв (ЗП) блискавковідводів та опор повітряних ліній електропередачі (ЛЕП) при дії аперіодичних імпульсів напруги з параметрами 1,2/50 мкс та струму з параметрами 8/20 мкс і 10/350 мкс. Для цього використано теорію електротехніки, програмні засоби моделювання перехідних процесів та методи натурного моделювання. Було визначено параметри елементів електричного кола додаткового формуючого блоку для створення грозових імпульсів струму з параметрами 10/350 мкс за допомогою вимірювального комплексу типу ІК-1У. Вдосконалено комплекс типу ІК-1У, що дозволило визначати імпульсний опір ЗП блискавковідводів та опор ЛЕП при дії імпульсів струму 10/350 мкс, 8/20 мкс та напруги 1,2/50 мкс. Модернізований прилад дозволяє проводити вимірювання відповідно з сучасними міжнародними вимогами. Бібл. 9, табл. 1, рис. 3.

Ключові слова: **опір, заземлювальний пристрій, грозовий імпульс струму (напруги), вимірювальний комплекс.**

Целью работы является создание измерительного прибора для определения сопротивления заземляющих устройств (ЗУ) молниеотводов и опор воздушных линий электропередачи (ЛЭП) при воздействии апериодических импульсов напряжения с параметрами 1,2/50 мкс и тока с параметрами 8/20 мкс и 10/350 мкс. Для этого использовано теорию электротехники, программные средства моделирования переходных процессов и методы натурного моделирования. Были определены параметры элементов электрической цепи дополнительного формирующего блока для создания грозовых импульсов тока с параметрами 10/350 мкс с помощью измерительного комплекса типа ИК-1У. Усовершенствован комплекс типа ИК-1У, что позволило определять импульсное сопротивление ЗУ молниеотводов и опор ЛЭП при воздействии импульсов тока 10/350 мкс, 8/20 мкс и напряжения 1,2/50 мкс. Модернизированный прибор позволяет проводить измерения в соответствии с современными международными требованиями. Библ. 9, табл. 1, рис. 3.

Ключевые слова: **сопротивление, заземляющее устройство, грозовой импульс тока (напряжения), измерительный комплекс.**

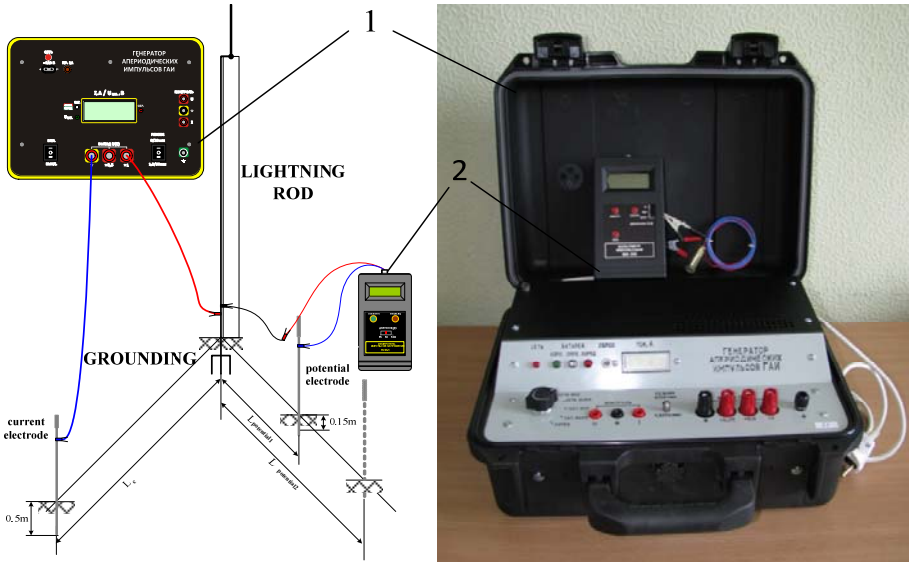
Problem definition. Provision of permissible values of the parameters of grounding devices (GDs) of electric power stations and substations, separately installed lightning arresters and overhead line's supports within the limits defined by regulatory documents, is a prerequisite for the reliability of the operation of expensive equipment and electrical safety of personnel. In order to control the state of the GDs of electric power stations and substations in Ukraine, the method of electromagnetic diagnostics is the most widespread [1, 2]. One of the procedures of its experimental stage is to determine the impedance of lightning arresters, installed separately, and the supports of overhead lines with lightning protection cables. In the domestic normative document [3] there is no concept of «impulse impedance of the GD», but in international requirements, in particular in [4-6], the impedance of the lightning arresters and overhead lines' supports is defined as «the ratio of the peak value of the voltage to the GD to the peak value of the current, which flows in the GD, under the action of the current pulse with the given time parameters».

In the world, there are a number of devices that allow to determine the impulse impedance of the GD. The paper [7] describes a powerful stationary generator that generates pulses of artificial lightning current with amplitude ±(100-200) kA for fundamental and applied research. The papers [8, 9] provide a detailed analysis of the most commonly used portable devices, including: Polish WG-407, WG-507 and MRU-200, Japanese PET-7, ZED-meter of the US, Ukrainian IK-1U and Russian impedance meter [8]. At the same time, it should be noted that among the listed devices, only three allow measurements when simulating a thunderstorm pulse, namely: WG-507 with pulse 4/10 μs, MRU-200 – 4/10 μs and 10/350 μs, and IK-1U with pulses of 1.2/50 μs and 8/20 μs. Other devices allow measurements to be made under the influence of pulses of current or voltage with non-normalized parameters with pulse duration of several to hundreds of microseconds and a front from tens of nanoseconds to 1 microsecond. For example, PET-7 generates a pulse with a gain of 1 μs and a duration of 256 μs

or ZED-meter – a rectangular pulse duration 1.4 μs. Among the above-mentioned, the complex IK-1U has the largest measuring current, the value of which in the short-circuit mode is 25 A while for other ones measuring current is in the range from 0.5 A to 5 A. The maximum energy of the measuring pulse of the IK-1U device, which is 0.3 J, lies in the middle of the range compared with other instruments for which it varies from 0.017 J to 1 J [8].

The complex IK-1U developed by the specialists of the Scientific-&-Research Planning-&-Design Institute «Molniya» of the NTU «KhPI» is designed to measure the impulse impedance of lightning arresters, standing separately, and the impedance of the transmission lines without disconnecting the lightning protection cable. The IK-1U device is entered in the state register and consists of a generator of aperiodic pulses ГАИ-3 (see item 1 in Fig. 1) and a pulse voltmeter ВИ-6М (see item 2 in Fig. 1). In accordance with the current international requirements [4-6], for simulating the direct lightning strike, it is necessary to check the reaction of the GD to the pulse voltage of 1.2/50 μs and the current pulse 10/350 μs, and to simulate the pulsed currents induced in the metal structures and communications of the object with distant lightning strikes – 8/20 μs. The carried out analysis shows that there are no devices in the world that can carry out universal measurements in all three of the above modes.

The goal of the work is the creation of a measuring device for determining the impedance of GDs of lightning arresters and overhead lines' supports during the action of the aperiodic pulses of 8/20 μs, 10/350 μs and 1.2/50 μs.



a *b*

Fig. 1. Scheme of measurements (*a*) and external view (*b*) of the complex type IK-1U

Research materials. There are two ways to achieve this goal:

- development of a new device, which can operate in three modes of formation of the specified pulses;
- improvement of the existing instrument.

The first way involves the need to develop a new circuit design solution. Here, in the case of generating a current pulse with amplitude of 25 A at 10/350 μs temporal parameters, as in the device IK-1U for a mode of 8/20 μs, the capacity of the capacitors of the device should increase from 2.35 μF to 7500 μF while maintaining the operating voltage of 1 kV with a corresponding change in the forming elements. That is, the new device will have such mass-sized dimensions, which will be either stationary, or mounted on the automotive base. This will greatly complicate its use in field conditions as part of the implementation of electromagnetic diagnostics of the GDs.

The second way is to improve the existing complex of type IK-1U due to «stretching» the duration of the current pulse in the mode of 8/20 μs at reducing its amplitude. This can be achieved by developing a special forming unit and expanding the pulse voltmeter measurement range. In addition, this will minimize costs by maintaining the main circuitry solutions of the generator.

The forming unit of the device is proposed to be executed in the form of a set of RLC-elements, which should be connected to the output of the generator of the complex IK-1U in the mode of 8/20 μs, which will allow the use of already developed complexes without their further elaboration. The following assumptions were made to evaluate the parameters of the elements of the forming unit of the complex: due to the fact that the period of follow-up of the pulses of IK-1U significantly exceeds the required pulse duration of 350 μs (the frequency of follow-up of about 3 Hz), we can consider the generator IK-1U as a capacitive energy storage device C1 with a known discharge circuit (see Fig. 2,*a*). In the 8/20 μs mode, the capacity is 2.35 μF, the initial voltage on the capacitor C1 is 1000 V, the inductance L1 = 56 μH, and the resistance of R1-R4 is 1 Ω, 7.5 Ω, 6 Ω and 9 Ω, respectively. Resistor R1 acts as a load. Determination of the parameters of elements of the forming block of the complex was performed on the basis of the calculation model in the demo version of the MicroCap software complex. To increase the duration of the current pulse to 350 μs, a high inductive throttle L2 was used, to provide a

10 μs front a forming capacitor C2 and a resistor R5 were introduced, and the resistor R6 smoothes the oscillation processes that arise in the discharge circuit.

Nominal values of L2, C2 and R6 elements were determined in the Transient Analysis mode, taking into account the existing nominals of real elements. The results of the simulation of the IK-1U complex with a forming block in the mode of 10/350 μs (see Fig. 2,*b*,*c*) show compliance with the set conditions for temporal parameters, with the amplitude of current not to exceed 1.1 A, and the maximum voltage on the elements of the block will be: L2 and R6 – 600 V, C2 – no more than 10 V, and R5 – no more than 5 V. Obtained values were used when selecting existing elements. As C2, two consecutive connected polar capacitors with capacity of 47 μF and operating voltage 25 V each, resistor R6 – 1.2 kΩ type MJIT-0,125, throttle of our own manufacturing (due to the absence of industrial ones with inductance of 18 mH) with resistance less than 0.5 Ω, operating voltage up to 500 V and current of 1.1 A.

As can be seen from the pulse simulation results, the pulse duration is 341 μs at amplitude of 1.04 A, pulse front of about 12.8 μs, which, with allowance of ±20 % [5], practically meets the set requirements. Thus, with the help of simulation, the parameters of the elements of the forming block for the current pulse 10/350 μs were determined using the standard generator of the measuring complex IK-1U. In addition, it is proposed to use modern power supply elements and capacitor types during manufacturing of new complexes on the basis of the IK-1U device and, respectively, to improve the charging unit and to add a voltage control module. This will reduce the number of large size capacitors from 21 to 4, extend the service life of the battery pack of the IK-1U, increase the ease of mounting and replacing the batteries. The proposed changes allow to significantly reduce the total weight of the complex (from 14 kg to 5.5 kg). In addition, the transition to a more modern elemental base allows to free space in the case and to mount a forming unit of 10/350 μs into the existing complex IK-1U, as its integral module.

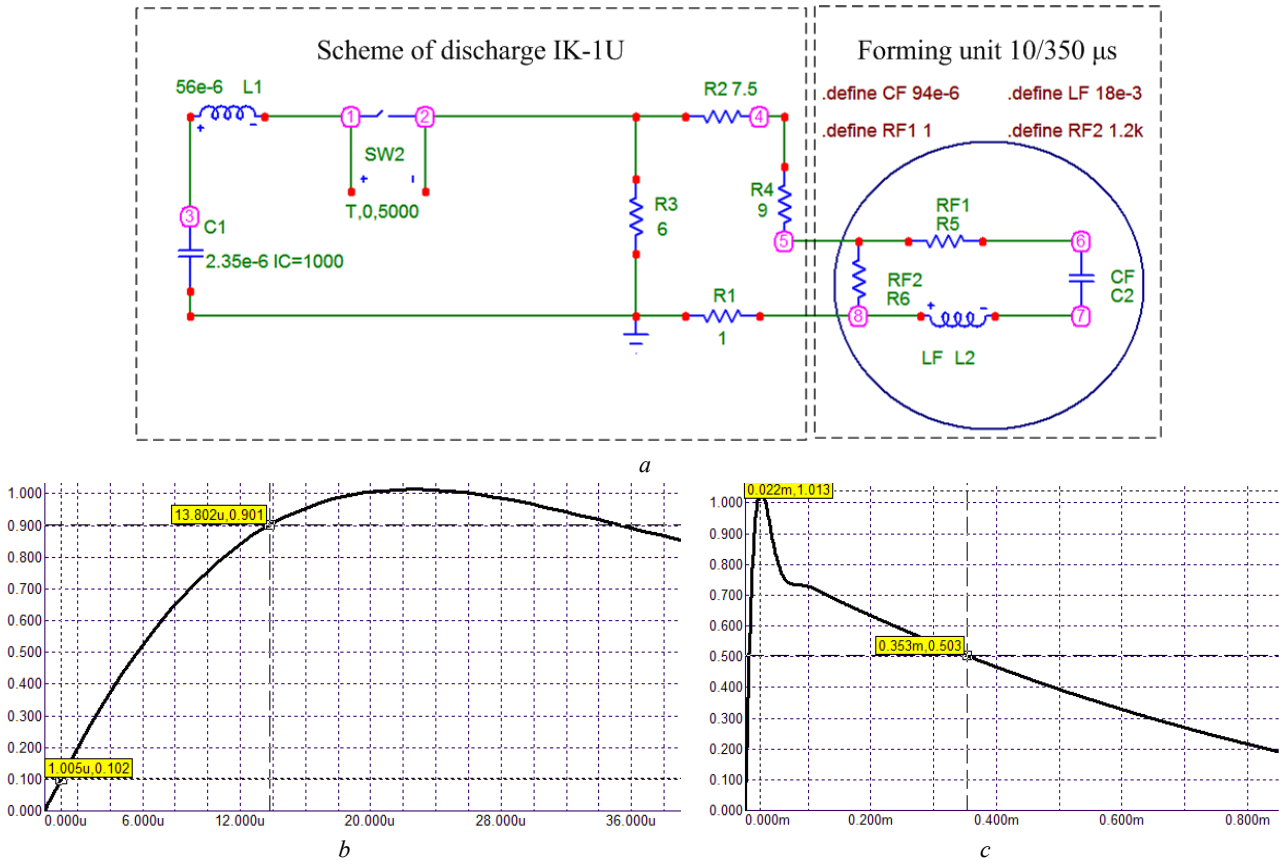


Fig. 2. Electrical circuit of the IK-1U class with the forming block (*a*) and the result of simulating the front of the pulse current (*b*) and its duration (*c*) in the software complex MicroCap

Table 1 shows the technical characteristics of the advanced complex IK-1U with the forming unit.

According to the simulation results, a layout of the forming unit in the form of an additional block and a complex of IK-1U with a modernized power supply system was created (see Fig. 3,*a*). Figures 3,*b*,*c* present the oscillograms of the front and the duration of the current pulse.

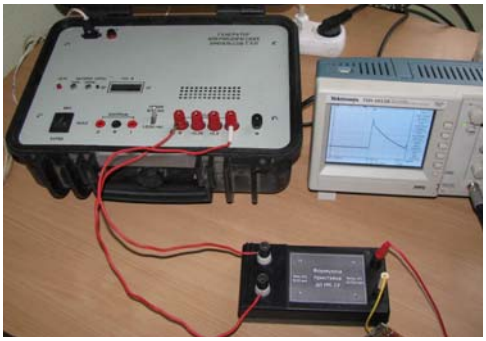
The indicated layout has been tested at performing electromagnetic diagnostics of the state of the GDs of over 100 active electrical substations of Ukraine.

Thus, the use of the forming unit in the complex IK-1U allows to obtain a current pulse with the following temporal parameters: the duration of the front 10±2 μs at the level of 0.1-0.9 from the amplitude and pulse duration 350±35 μs at the level of 0.5 from the amplitude. Completion of the modernization of the complex type of IK-1U allowed to obtain the necessary result at a minimum cost with the possibility of using existing systems.

Table 1

Characteristics of the complex IK-1U

Name of the parameter or characteristic	Value
Front of the pulse (at the levels 0.1-0.9 of the amplitude), μs	1.2 ± 0.1; 8 ± 0.8; 10± 2.0
Duration of the pulse (at the level 0.5 of the amplitude), μs	50 ± 5; 20 ± 4; 350 ± 35
Maximum amplitude of generated voltage pulses (in the mode of 10/350 μs), V	1000 (600)
Voltage pulses amplitude measurement range, V	0.5 – 200
Maximum amplitude of generated pulses (in the mode of 10/350 μs), A	25 ± 5 (1±0.05)
Range of measurements of current pulse amplitude, A	0.1 – 25
Relative error of measurement of amplitude of pulses of current and voltage %, no more	10
Power supply	from the network; from the built-in battery



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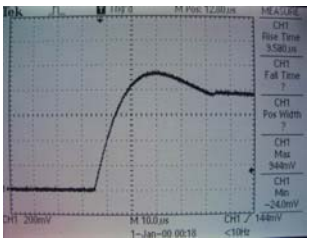

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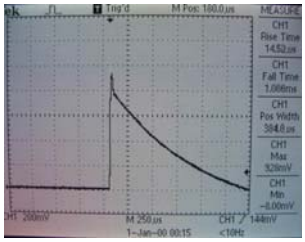

c

Fig. 3. External view of the forming unit in the form of an additional block with IK-1U (*a*) and the oscillograms of the current pulse front (*b*) and its duration (*c*)

Conclusions.

1. An analysis of the existing devices for measuring the impedance of the GDs is carried out and the need to create a device with test pulses of current of 8/20 μs, 10/350 μs and of voltage of 1.2/50 μs is shown.

2. The parameters of the elements of the forming block for the current pulse 10/350 μs are determined at utilization of an existing standard generator of the measuring complex of the type IK-1U.

3. The practical implementation of the forming block and the complex of type IK-1U with a modern element base is realized. The testing of their operation has been carried out on more than 100 active power facilities of Ukraine.

4. An autonomous power supply unit has been upgraded, which greatly reduced the mass and overall dimensions of the complex, as well as will allow the forming block to be mounted directly into the housing of the complex IK-1U.

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