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New type of impulse quenching line lightning protection device

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***Abstract* — To prevent lightning faults on 110 kV overhead lines operated without a ground wire, it is necessary to use special devices capable of withstanding the multiple currents of a direct lightning strike. This article is dedicated to one of such promising devices - a closed-type impulse quenching line lightning protection device (IQ LLPD). To demonstrate the performance of the device a complex of research electrical tests is described with a detailed description of unique techniques.**

Keywords — lightning protection, impulse quenching line lightning protection device, overhead power lines, multichamber system, direct lightning strike, arc of follow-up current, arc impulse quenching.

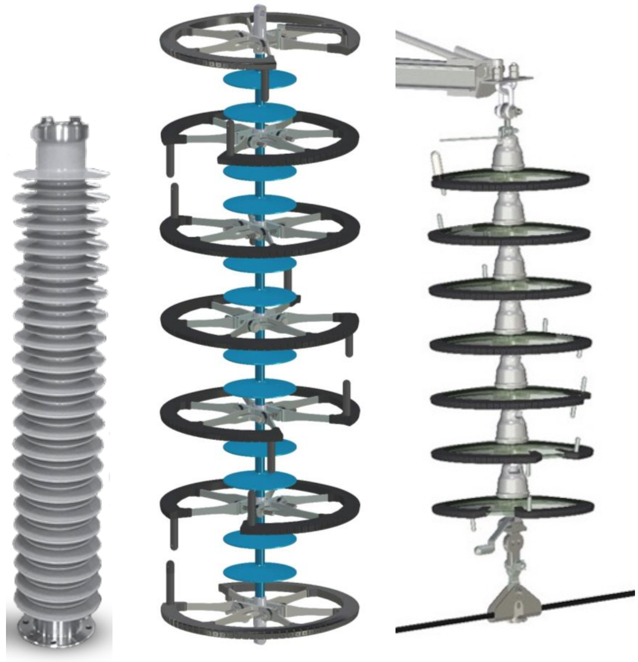
I. Introduction

To prevent lightning faults on 110 kV overhead lines operated without a ground wire, it is necessary to use special devices capable of withstanding the multiple currents of a direct lightning strike. This article is dedicated to one of such promising devices - a closed-type impulse quenching line lightning protection device (IQ LLPD). To demonstrate the performance of the device a complex of research electrical tests is described with a detailed description of unique techniques.

Key words: lightning protection, impulse quenching line lightning protection device, overhead power lines, multichamber system, direct lightning strike, arc of follow-up current, arc impulse quenching.

Currently, the main means of protection against lightning faults of overhead power lines of 110 kV, for various reasons operated without a grounding wire, are metal-oxide surge arresters (SA) (fig. 1 a), as well as multichamber arrester (MCA) (fig. 1 b), and multichamber insulator arrester (MCIA) (fig. 1 c).

Each device has its own advantages and disadvantages, as well as application limitations. For example, SA have a series of advantages, such as: fast response time, deep overvoltage limitation, compactness, high reliability (with strict observance of manufacturing technology and correct choice of capacity class, usually for protection against direct lightning strike - class four or five).



a) b) c)

Fig. 1. Appearance of lightning protection devices of ALs 110 kV on a scale:

a – SA-110; b – MCA-110; c – MCIA-110.

The disadvantages of devices are: the difficulty of technology used in the production of metal-oxide varistors (MOV) (the main working elements), high cost, the need for condition monitoring and regular preventive inspections. In today's highly competitive lightning protection industry there are also cases of varistors declining in quality due to manufacturers' desire to make their products cheaper, as well as cases of SA with insufficient capacity class to protect overhead lines from direct lightning strikes (DLS).

It is possible to get rid of the disadvantages associated with operating SA directly under operating voltage by separating them from the phase conductor by means of a spark air gap. However, in this case, to protect overhead lines without a lightning protection cable, it is required to use arresters with a 2-3-fold increase in the capacity, which significantly reduces the economic attractiveness of such a solution.

Multichamber arrester and MCIA - lightning protection devices, using a different, than arresters, physical principle of operation to prevent overhead line faults - the so-called quenching of the follow current arc by means of discharge chambers [1]. The indisputable advantage of MCA and MCIA is the ability, when triggered, to lead the arc out of the working element and dissipate its energy in the surrounding space, which provides resistance to repeated effects of DLS currents, as well as simplicity and reliability of design. Separately, we should highlight the conceptual feature of MCIA, which consists in placing the main working element - multi-chamber system (MCS), directly on the fins of the glass insulators of the festoon, thereby providing the most perfect design in terms of technology of lightning protection device placement (Fig. 1, c).

To the disadvantages of MCA and MCIA can be attributed a limitation in application, associated with the maximum value of short-circuit current (SC) in the place of installation of the device. This limitation is due to the specifics of zero quenching of the follow current, which can flow through the MCS of the arrester for quite a long time - up to 7 ms. Exceeding the accompanying current amplitude above the recommended maximum value leads to intensive erosion of electrodes and chamber walls, and, consequently, to accelerated depletion of the arrester working life.

«Streamer» company has developed a new class of lightning protection arresters, manufactured according to an innovative technology and possessing all the advantages of SA and MCA, but deprived of their disadvantages..

II. Design description

A. Selecting a Template (Heading 2)

Closed-type impulse quenching line lightning protection device (IQ LLPD) is a device designed to protect 110 kV overhead lines from outages, caused by lightning, including DLS in the phase wires. Main working elements of IQ LLPD are discharge modules (DM), which are MCS made in the form of disks (Fig. 2, a, b) of polymer material with metal electrodes, placed inside. Between the electrodes are formed miniature discharge chambers. In contrast to the MOV, where current flows through multiple parallel channels, in DM current pathway is one - through a system of electrodes, combined into a single continuous circuit. The electrically connected DM in series are assembled into a column, which is placed inside a fiberglass housing. To provide the required characteristics in terms of AC withstand voltage, as well as waterproofing, the housing is covered outside with a polymer shell with fins (Fig. 2, c).

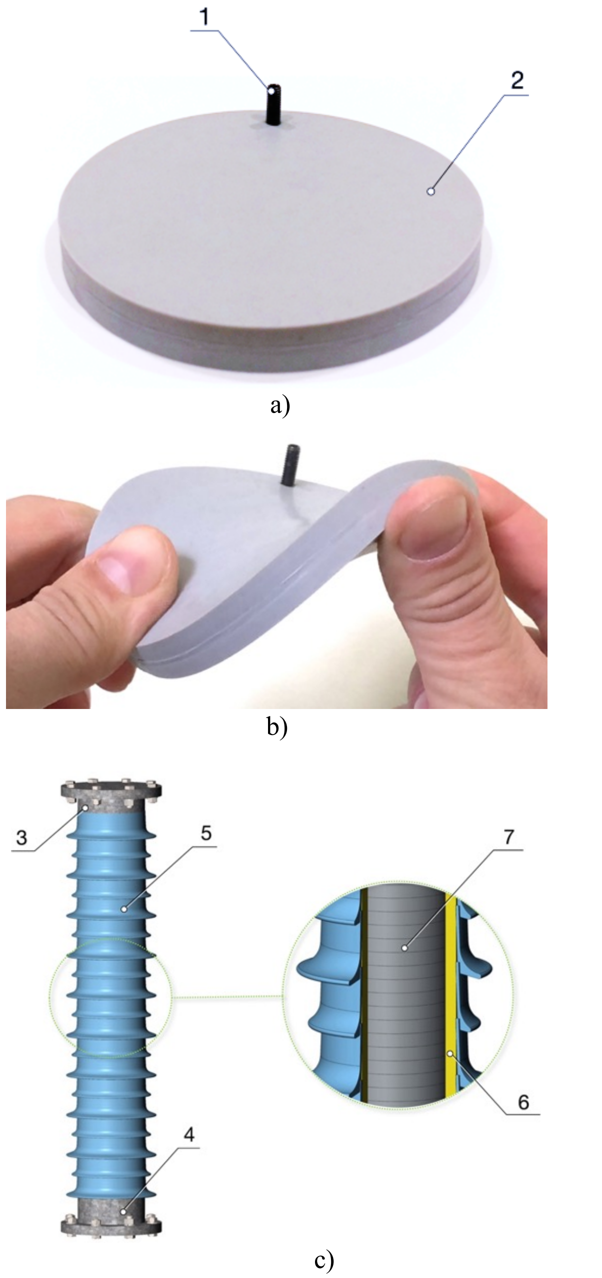


Fig. 2. IQ LLPD-110 construction: a and b - a single discharge module; c – IQ LLPD exterior view: 1 - DM terminal electrode; 2 - DM body; 3 - upper end fitting; 4 - lower end fitting; 5 - shell; 6 - housing; 7 - column of discharge modules

Placement of the MCS inside the fiberglass tube allowed to significantly reduce the device dimensions and make them comparable with the average values of the SA dimensions.

Installation of IQ LLPD on 110 kV overhead lines is performed electrically parallel to the line insulation with a spark air gap (SAG) between the wire and the high-voltage arc electrode (Fig. 3). The presence of the SAG isolates the IQ LLPD from the continuous effects of the mains operating voltage and also eliminates triggering from internal mains overvoltages, which has a beneficial effect on the reliability and durability of the device. The activation of the IQ LLPD is carried out only in the event of a SAG breakdown due to a lightning overvoltage.

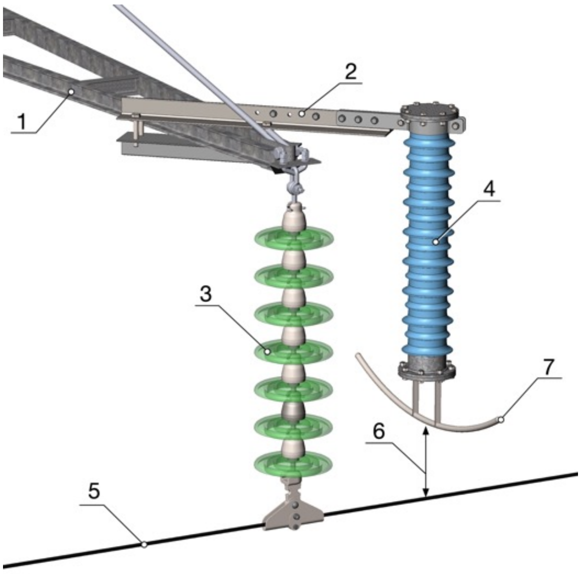


Fig. 3. Placement IQ LLPD on overhead lines of 110 kV: 1 - tower cross-arm; 2 - external cross-arm; 3 – cup-and-pin insulators; 4 – IQ LLPD; 5 - wire; 6 - spark air gap; 7 - high-voltage electrode

Principle of operation of the IQ LLPD is based on ensuring the value of the total voltage drop across the spark gaps is much higher than the level of the applied mains voltage, which is restored on the arrester immediately after the lightning current pulse. This prevents the occurrence of short circuits, and the overhead line continues its uninterrupted operation (Fig. 4).

Construction of MCS of IQ LLPD, made in the form of DM, differs significantly from the construction of MCS, used now in mass-produced MCA in the shape and number of electrodes, logic of their placement, as well as the design of arc discharge chambers and so forth. These differences allowed to provide the dense placing of DM inside the tube case and to achieve a significant increase of operating speed - up to 0,5 ms from the beginning of lightning impulse up to complete restoration of network voltage. In fact, with such speed of operation the accompanying current flowing through the arrester is practically excluded, which allows to remove the limitation on its maximum value inherent in commercially available MCA and gives an opportunity to significantly expand the area of IQ LLPD application.

III. Comparison of DM manufacturing technology with MOV

Manufacturing of MCS in the form of DM is a fundamentally new technology, which, in contrast to MOV, has a great potential to optimize the design and improve manufacturability.

One of the important advantages of DM in comparison with classical MOV is simplicity of manufacturing and incomparably less requirements to manufacturability of processes and complexity of used equipment (Fig. 4).

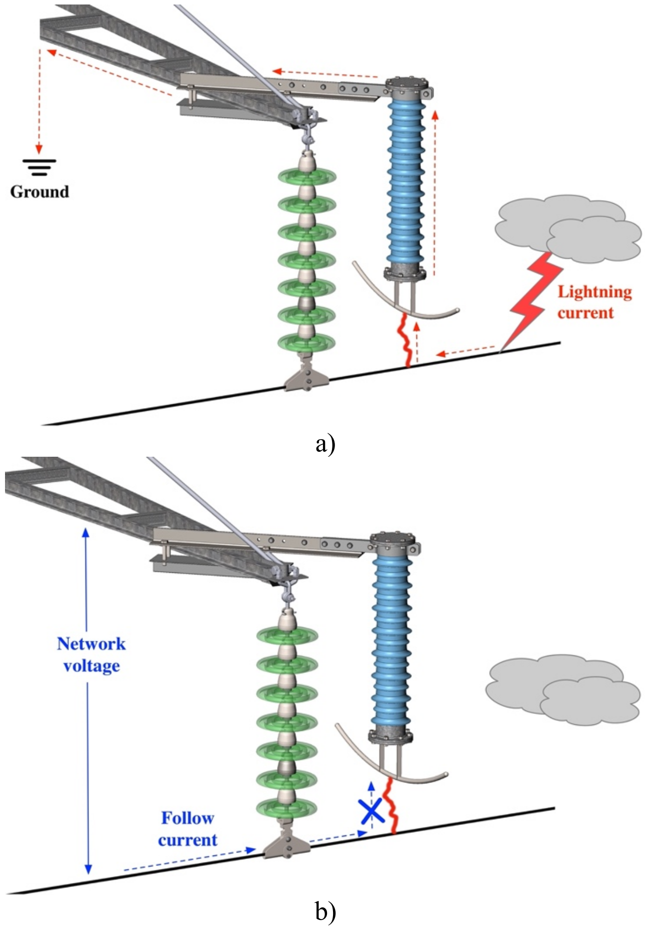


Fig. 4. Illustration of the principle of operation of IQ LLPD-110: a - flow of impulse lightning current; b - prevention of follow current flow

When DLS currents pass through the column of DM on miniature spark gaps MCA, as a result of the discharge energy is released, which is spent on heating and mechanical work on the expansion of the channel inside the chambers of DM. The heat, released from each DLS impulse is absorbed by the DM material and heats it up by no more than approximately 10˚C, and the mechanical energy, spreading as deformation waves, is quickly attenuated in the DM material and housing thickness.

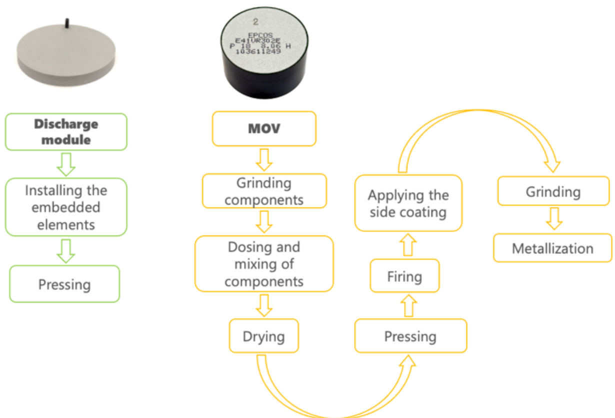


Fig. 5. Comparison of DM and MOV manufacturing technology

As opposed to varistors, DMs are virtually insensitive to overheating because all of their constituent materials retain their characteristics up to +250˚C. Such temperatures are unachievable under normal modes of operation of IQ LLPD and even under extreme overloads in the test laboratory, where several dozens of DLS current pulses are continuously applied to the arrester at intervals of several minutes. Thus, the flowing currents cause a weak temperature accumulating effect, which allows the IQ LLPD to withstand multiple exposures to DLS currents.

DM ability to maintain operability under repeated DLS impacts makes IQ LLPD a competitor of SA of the highest, fifth class of carrying capacity.

On the basis of technology of MCS creation in the form of DM wide opportunities of its design adaptation for a number of new devices of different voltage classes, as well as conditions of application, in particular, creation of simplified devices of overhead line protection, equipped with lightning protection cable, where DLS into the phase wire are excluded.

To confirm the technical characteristics a series of exploratory electrical tests of IQ LLPD-110 according to the requirements [4], demonstrating the basic performance of the device.

The list of tests included:

- follow current interrupting test;
- test of insulation protection capability against overlapping;
- one-minute alternating voltage test.

IV. Follow current interrupting test

This type of test demonstrates the arrester's ability to prevent short circuits when lightning overvoltages occur on the overhead line.

Tests are carried out on a specially designed high-voltage test bench, which simulates the simultaneous effects of real lightning and network parameters on the test piece (Fig. 6).

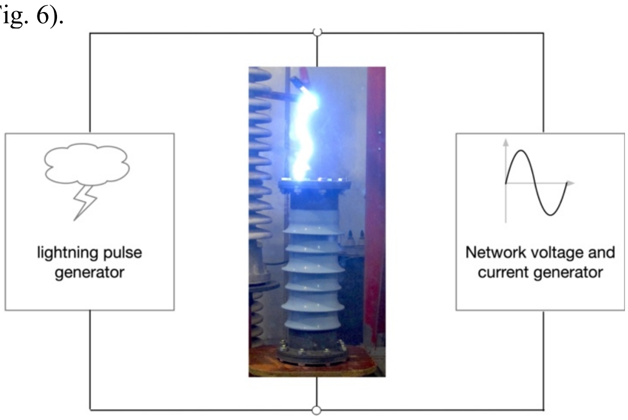


Fig. 6. Block scheme of the test bench

Pulse of lightning is simulated by a generator of voltage and current pulses. Parameters of influence: amplitudes of lightning currents - up to 30 kA, duration up to half-fall - up to 100 µs. According to calculations [2], these parameters in their maximum expression correspond to 95% probability of occurrence of possible lightning currents according to [6], which will flow through one, nearest to the place of lightning strike. Impacts of the network are modeled by an oscillating circuit with a voltage of up to 30 kV and a short-circuit current of up to 25 kA.

Limited maximum voltage of the vibration circuit does not allow to test a full-size sample of 110 kV, therefore, the experiments were carried out on a sample of shortened size (Fig. 6).

According to the test program to each sample was applied 10 impacts of lightning current of back flashover and direct lightning strikes with different amplitudes from 3 to 30 kA. At the same time, the mains voltage was restored on the sample, under the action of which the follow current tended to flow along the triggered arrester.

The design of MCS - the main working element of the IQ LLPD was developed so that the follow current flow was excluded, and the whole process from the beginning of lightning impulse effect to restoration of the mains voltage took not more than 1 ms.

Test results were evaluated by oscillograms. Fig. 7 shows typical oscillograms of the voltage applied to the sample and the current flowing through it. Normal operation of the IQ LLPD assumes the absence of the follow current after the end of the pulse current with the restoration of the mains voltage to its normal value.

The criterion of successful passage of tests was the absence of follow current flow for all test modes on all samples, as well as the absence of damage to the housing and the MCS.

As an experiment on one of the specimens, a life test was conducted, which consisted in the continuous repetition of the test program for the follow current interruption until the first leakage of the follow current. The test specimen withstood more than six repetitions of the standard test program, i.e., more than 60 exposures, 40 of which were DLS current pulses.

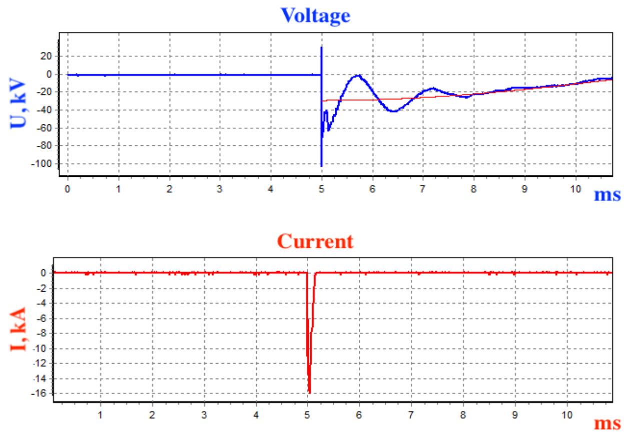


Fig. 7. Typical oscillograms of the voltage and current flowing through the IQ LLPD during the breaking capacity tests

According to calculations, carried out in [5], for each arrester, installed on overhead line 110 kV, for 30-year operation term is expected not more than 2 impacts of DLS currents at lightning intensity of 100 h/year. Thus, it can be stated that the IQ LLPD-110 has more than a considerable reserve of service life.

V. Testing of insulation protection capability against overlapping

This type of tests was carried out in order to check the possibility of line insulation protection by the arrester against impulse overlapping at occurrence of atmospheric overvoltages.

For the tests the full-size IQ LLPD-110 was placed parallel to a garland of seven cup-and-pin insulators, typical for overhead lines of 110 kV voltage class (Fig. 8). The structure was suspended on the grounded cross-arm. To the wire, installed on the insulator garland, the high-voltage lead of the voltage pulse generator (VPG) was brought. Between the wire and the IQ LLPD electrode an adjustable SAG was made.

The task of the test was to determine the maximum length of the SAG, at which there was no flashover.

The test methodology implied applying a series of voltage pulses with a steep front of both polarities to the insulator garland with a step-by-step increase of the SAG length. In order to determine the discharge path of each experiment, a photo shoot was carried out.

During the tests it was determined that reliable coordination of the operation of the line-insulated IQ LLPD is maintained at a maximum SAG value of 300 mm.

Figure 8. Testing of insulation protection capability against overlapping

VI. One-minute alternating voltage test

The only function of the IQ LLPD is to protect 110 kV overhead lines from outages caused by lightning. The arrester is not designed to protect against internal line overvoltages, and therefore must be tuned against them by a sufficient value of the SAG.

The purpose of this type of test is to determine the minimum value of the SAG at which the IQ LLPD will not trigger due to the effects of internal mains surges.

The setting of the IQ LLPD is similar to the previous type of test, the only difference being that a voltage transformer is connected to the wire on the insulator strand instead of the VPG.

The test technique is suggests applying to the arrester the alternating voltage of 200 kV of industrial frequency and its exposure for 1 minute with a continuous exposure to rain.

In order to determine the minimum value of the SAG its step-by-step reduction is carried out until the first tripping or overlapping of the arrester.

The tests allowed us to determine the minimum value of the SAG of 200 mm, at which there is no triggering or overlapping of the arrester within 1 minute.

Conclusions

- The article describes the design and principle of operation of the innovative device IQ LLPD-110, designed to protect 110 kV overhead lines from DLS in the phase wires.
- IQ LLPD-110 has advantages of SA, such as small size, high speed of operation and wide application area, as well as advantages of MCA - resistance to multiple effects of currents of DLS and a relatively low cost.
- Technology of DM manufacturing, unlike MOV, has a great potential for development.
- Technical solutions used in the design of IQ LLPD-110 allow them to be used to create a large group of lightning protection devices of overhead lines of different voltage classes and for different application conditions.
- Conducted research electrical tests confirm the operability of IQ LLPD-110.

References

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