

Lightning Protection of Electric Power Overhead Distribution Lines by Long-Flashover Arresters in Russia

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SUMMARY

A simple and effective method for lightning protection of power overhead distribution lines by long flashover arresters (LFAs) is presented. Even large lightning currents do not pose any threat to these arresters because the discharge develops in the air and not inside the device.

LFAs, which are based on the creeping discharge effect, increase the lightning flashover length significantly and thus eliminate Power Arc Follow (PAF). To protect a line against induced overvoltages, a single arrester should be mounted on a pole. To protect a line against direct lightning strokes, LFA-M arresters should be mounted in parallel with each insulator.

For covered-conductor overhead lines (CCL) using conductors with three-layer insulation a new lightning protection approach is suggested, involving use of antenna-type long flashover arresters whose essential component is the protected conductor itself. The essence of antenna-type long flashover arresters (LFA-A) is that the arrester which is connected to the antenna gets flashed over well before the lightning leader comes in immediate contact with the line.

The toroid-shaped antenna made of a metal tube is mounted on the covered conductor's surface midway between the protector's edge and the piercing clamp with the help of the toroid fixation unit. As the lightning leader progresses from a thunderstorm cloud to the CCL a high potential gets induced on the LFA antenna. A voltage drop that develops between the electrode and the zero-potential conductor core gives rise to development of a creeping discharge. Even before the lightning leader hits the line the creeping discharge channel flashes over the covered conductor's surface. Thereby the conductor insulation gets bypassed by the discharge channel and thus protected against puncture.

LFA's main applications and field experience are presented.

KEYWORDS

Lightning overvoltage, power arc follow, long flashover arrester

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1. INTRODUCTION

Outages of overhead power lines due to lightning strokes are one of the main causes of shortages of electric supplies and economic losses of power utilities. Widely separated pole-top metal oxide arresters can protect a distribution line against induced overvoltages. The main problem of using pole-top metal-oxide arresters is that they can be destroyed at direct lightning stroke to an overhead line [1].

In many countries, covered conductors are used for MV overhead lines. Such conductors have multiple benefits compared to bare conductors but there is a problem of conductor burndowns by Power Arc Follow (PAF), which occurs after lightning overvoltage and flashover of insulator. Arcing horns or similar devices that are used in some countries for protection of covered conductors against conductor burndowns do not protect overhead lines from lightning outages and have to be replaced after several operations.

In Russia [2], long flashover arresters (LFAs) developed by Streamer Electric Company are used for lightning overvoltage and conductor burn protection of 10 kV overhead lines [3-5]. The operating principle is based on extending the impulse flashover channel on the arrester surface through the creeping discharge effect. Owing to a long flashover length, the power arc gets extinguished and the overhead line continues operation without tripout. The main advantage of LFA is that the current passes outside the device and flows along the arrester surface. Therefore, the arrester cannot be destroyed by excessive current, even at direct lightning stroke. LFA's construction is reliable and relatively simple. There are several LFA types.

2. MAIN APPLICATIONS

The Loop type LFA (LFA-L) consists of a piece of cable with steel cord inside, which is bent in a loop and connected to the pole with a clamp (Fig. 1). A metal tube is placed over the insulated loop in its middle part forming, together with the line conductor, a sparkover air gap. At one arm of the loop intermediate ring electrodes are installed. The loop is at the same potential as the structure. Due to a relatively big capacitance between the metallic tube and the steel cord inside the cable, the tube is practically at the same potential as the pole.

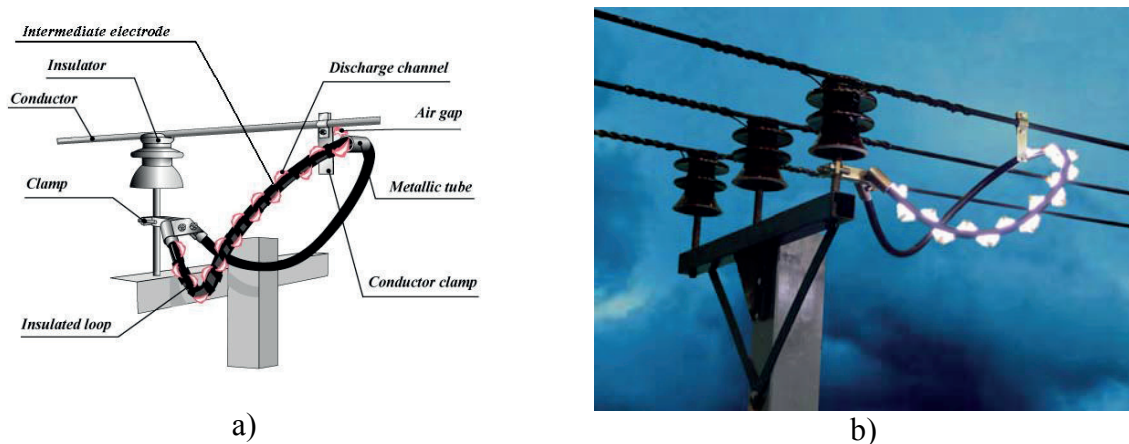


Fig. 1. Loop-shaped LFA: a – sketch; b- photo of tests.

Therefore an overvoltage occurring between the line conductor and the pole will also occur between the metal tube and the line conductor. If the overvoltage is large enough, the sparkover gap will break down and the overvoltage will occur between the metal tube and the

steel cord inside the cable to its insulation. Due to the overvoltage, a creeping flashover develops from the metal tube to a clamp of the insulated loop passing intermediate ring electrodes to the structure, thus completing the discharge circuit. The flashover length of a 10 kV LFA-L is 0.8 m. The intermediate electrodes have protrusions at opposite ends. Therefore, the flashover channel is broken into serially connected pieces of channels and due to this reason arc quenching is facilitated.

The Modular type LFA (LFA-M) arrester consists of two cable-like pieces with a resistive core (Fig. 2). There are also intermediate ring electrodes on its surface for the same purpose as for LFA-L (see above). The cable pieces are arranged so as to form three flashover modules 1 – 3, as shown in figure a below. The resistive core of the upper piece, whose resistance equals R , applies the high potential U to the surface of the lower piece at its middle. Similarly, the resistive core of the lower piece of the same resistance R applies the low potential 0 to the surface of the upper piece, also at its center. In this way, the total voltage U is applied to each flashover module at the same moment, and all three modules are assured conditions for simultaneous initiation of creeping discharges developing into a single long flashover channel with a total length of 1.5 m.

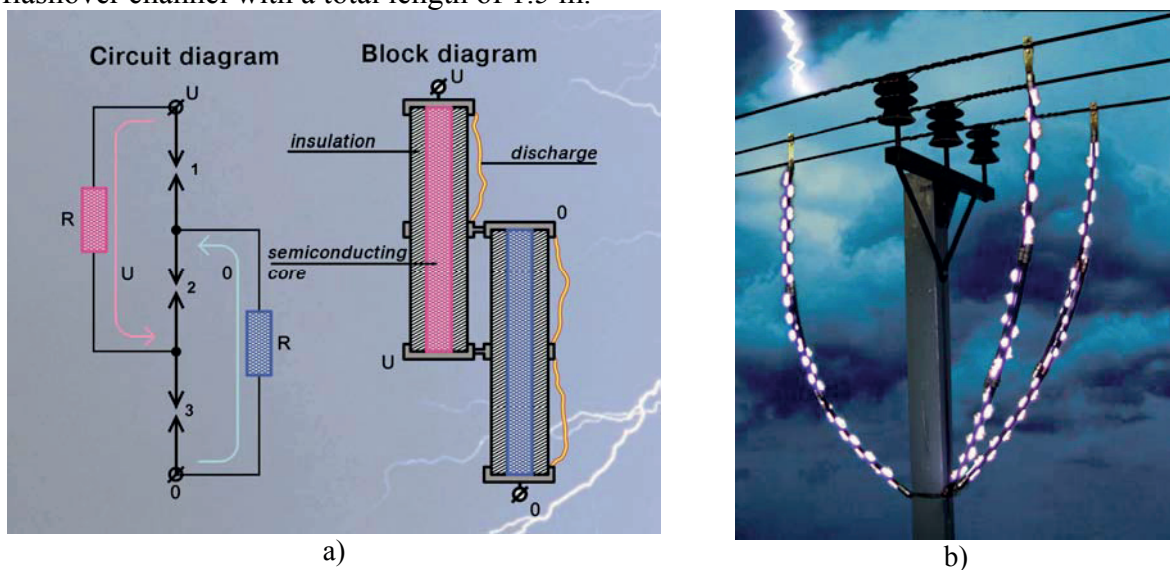


Fig. 2. LFA-M arrester for protection of 10 kV overhead lines
a) circuit and block diagrams; b) arresters testing.

3. PROTECTION AGAINST INDUCED OVERVOLTAGES

For overhead 10 kV distribution lines with insulated neutral (a three-conductor ungrounded system), which are used in Russia, single phase to ground fault currents are quite low (1 to 30A). Thus PAFs are effectively prevented by LFAs.

To eliminate high short circuit currents associated with two- or three-phase lightning flashovers to ground, LFA-Ls are recommended to be installed one arrester per pole with phase interlacing (Fig. 3). With such an arrangement, a flashover to ground results in a circuit comprising two phases, two arresters and two grounding resistors that limit the fault current and ease arc quenching. The higher are the values of the grounding resistance, the more effective is the LFA-L operation. A 10 kV LFA-L with flashover length of 0.8 m quenches fault currents up to 500 A. LFA-Ls can be also used for protection of power grids with neutral grounded via resistor.

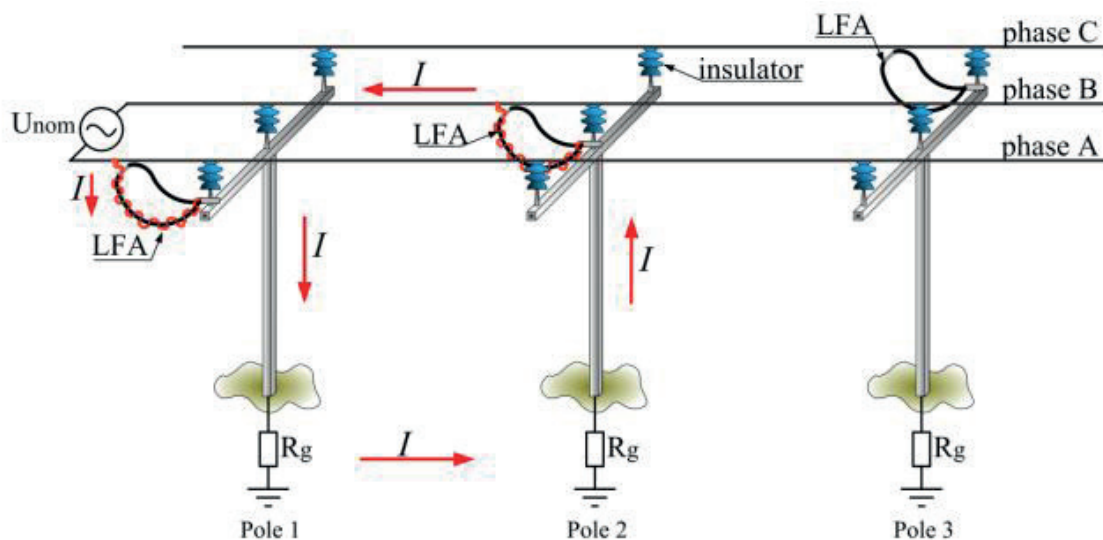


Fig. 3. LFA-L installation diagram on a distribution line

Four conductor overhead lines with grounded neutral have one phase to ground fault currents about several kiloamperes. In this case, the LFA-Ms with flashover length much greater than that of LFA-Ls can be used. They should be installed similarly, i. e. one unit per pole with phase interlacing.

4. PROTECTION AGAINST DIRECT LIGHTNING STROKES

A direct lightning stroke causes flashover of all the insulators on the affected pole. Therefore, in order to protect the line against a direct lightning stroke, LFA-Ms should be mounted on the pole in parallel with each line insulator. Phase-to-phase faults on a pole can give rise to follow-up current in the order of 10 kA or more. To quench such currents, flashover length of the LFA-M should be 1.5 m, i.e. much higher than that of LFA-L (0.8 m) which is intended to protect overhead lines against induced overvoltages.

5. FIELD EXPERIENCE

LFA-L and LFA-M are certified to meet the requirements of technical specifications and safety conditions of the Russian Government Standards.

Experimental exploitation of LFA-Ls started in 1999 and in the past three years more than 120 thousand arresters have been installed on various utilities including gas and oil companies equipment. As field experience has proved to be exceptionally successful, LFA-Ls are recommended by National guide for lightning protection of overhead MV lines as a main lightning protective means [2].

In October 2005, thirty arresters LFA-M were installed for experimental exploitation in St. Petersburg utility and in May 2006, 145 arresters were installed at an overhead line at Kuban utility (Southern Russia). Although the time is too brief to make sound conclusions, as of the present moment there have been no problems with the arresters exploitation.



Fig. 4. Installation of first experimental arresters (LFA-Ls) in St. Petersburg utility (Russia) in 1999.



Fig. 5. 6 kV overhead line in Kuban utility (Russia) equipped with LFA-Ms.

6. LIGHTNING PROTECTION SYSTEM OF 35 kV LINES WITH COVERED CONDUCTORS

Reliability of electric power supply over 35 kV overhead lines can be enhanced through application of covered conductors, which are capable to rule line trip-outs due to brief electric crosses under effect of wind and ice loads and prevent ground faults because of contacts with tree branches. A lightning protection system of 35 kV CCL, which would be capable of protecting conductors against burns as well, can be implemented through use of LFAs.

Application of a three-layer covered conductor with excellent insulating performance, makes it possible to make the conductor an essential component of the LFA. Covered conductors are suspended on a tangent tower in a manner that rules out damage to their insulation at points of their fixation to an insulator. This is achieved through use of a supporting clamp with a protector and a conducting polymeric grip at conductor fixation points.

Six piercing clamps (two to a phase) are mounted on all the three phase conductors at a distance of about 1.4 m either side of the edges of conductor-supporting metal protectors (see Fig. 6). High voltage laboratory tests with 1.2/50 μ s lightning overvoltage impulses showed the impulse strength of a composite insulator to be $U_{50\% \text{ ins}} = 250$ kV; however, by using the insulating properties of the three layer covered conductor, as shown in Fig. 6, the impulse strength of the suspension set becomes as high as $U_{50\% \text{ ins-cov. cond}} = 400$ kV. Thus the impulse strength of line insulation of all the three phases is raised to 400 kV.

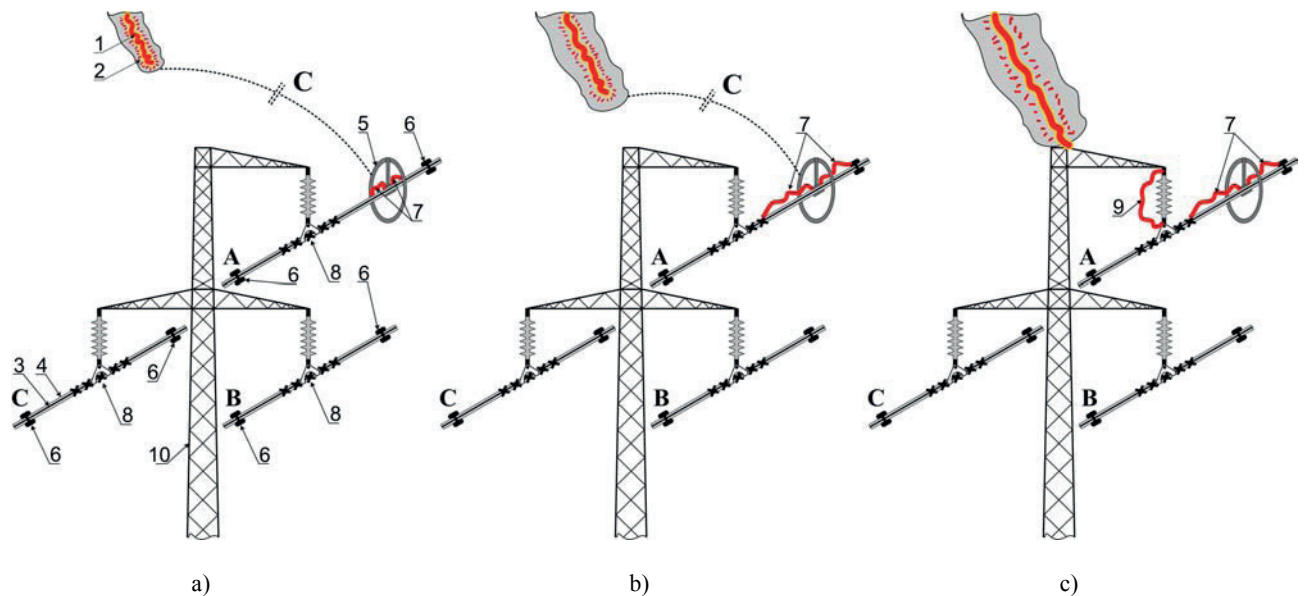


Fig. 6. Lightning protection of a 35 kV overhead line with covered conductors

a) The lightning is high above the ground, discharge channels start developing from the antenna fixation unit;

b) The lightning is close to the line, the covered conductor's section between a grip and a piercing clamp gets flashed over totally;

c) The lightning strikes the line, an insulator gets flashed over:

1 – lightning channel; 2 – space charge; 3 – conductor core; 4 – protective insulation; 5 – toroid-type antenna; 6 – piercing clamp;

7 – flashover channel over insulation surface; 8 – supporting clamp with protector; 9 – insulator flashover channel; 10 – tower.

The essence of antenna-type long flashover arresters (LFA-A) is that the arrester which is connected to the antenna gets flashed over well before the lightning leader comes in immediate contact with the line [6]. The toroid-shaped antenna made of a metal tube is mounted on the covered conductor's surface midway between the protector's edge and the piercing clamp with the help of the toroid fixation unit, which is further referred to as electrode. As the lightning leader progresses from a thunderstorm cloud to the CCL a high potential gets induced on the LFA antenna. A voltage drop that develops between the electrode and the zero-potential conductor core gives rise to development of a creeping discharge (Fig. 6, a). Even before the lightning leader hits the line the creeping discharge channel flashes over the covered conductor's surface (Fig. 6, b). Thereby the conductor insulation get bypassed by the discharge channel and thus protected against puncture.

A lightning stroke on a tower (Fig. 6, c) or on a line conductor results in an overvoltage on the conductor and on the protector, which is connected to the conductor via the discharge channel. The insulator gets flashed over as soon as overvoltage attains its flashover level. During a tower stroke most of the lightning overvoltage current flows first via the lightning flashover channel and next, via the tower to the ground (see Fig. 6, c). A part of the current flows by the creeping discharge channel over the conductor's surface to the piercing clamp and on over the line conductor.

When the lightning strikes a conductor the lightning overvoltage current flows by the lightning flashover channel over the conductor, across the piercing clamp and on by the insulator's lightning flashover channel and the tower body to the ground. The lightning overvoltage current is followed in the flashover channel by the power frequency current. As

the follow-up current crosses zero the power arc gets extinguished, and the line maintains uninterrupted supply of power without an outage.

Attention is drawn to the fact that an antenna on the covered conductor's surface warrants that the covered conductor's section between the piercing clamp and the protector (see Fig. 6) is flashed over its surface with voltage rising smoothly and thus presenting no hazard for the covered conductor's insulation.

Without an antenna, the flashover pattern for the insulator-covered conductor system is totally different, with no discharges on the covered conductor's surface before the lightning strikes a tower or a line conductor. By way of example, a lightning stroke on a conductor results first in an insulator flashover, the voltage being abruptly applied to the covered conductor's insulation in a steep impulse resulting in a puncture.

The combined flashover length over the affected insulator and covered conductor (Fig. 6) needed to assure extinction of the follow-up arc can be found from the following equation [7]:

$$L = \frac{U}{70I^{-0.41}} \quad (\text{at } 20 \leq I \leq 600 \text{ A}), \quad (1)$$

where U is the applied AC voltage, kV, and I , the follow-up current, A.

In isolated neutral grids, the follow-up current is capacitive single-phase fault current rarely in excess of 50 A. It follows from Eq. 1 that with the highest permissible phase voltage $U=U_{\text{ph, max}} = 1.15 \cdot 35 / \sqrt{3} = 23.3$ kV and the follow-up current $I = 50$ A the total flashover length that warrants quenching of the arc is $L \approx 1.7$ m. The flashover length of a 35 kV insulator is about 0.5 m. Thus the needed flashover length over the covered conductor's surface is about 1.2 m.

The antenna voltage at the instant of an approaching lightning leader was calculated with the help of the procedure described in [6] for the overhead line alternative shown in Fig. 6, the minimum lightning current I_l being assumed to be 5 kA. If the arrester gets actuated at this minimum, there is even less doubt about its operation at any larger lightning current.

Both a conductor and a tower can be struck by a lightning. The farther from the antenna the lightning is, the lower is the induced voltage on the antenna [6]. Computations were made for the worst-case LFA-A scenario, viz., for the mid-span stroke on a conductor, with the lightning channel offset by about 75 m toward a tower along the line. A successful operation of the LFA-A at a mid-span stroke guarantees its good performance with a lightning striking a tower.

Shown in Fig. 7 are the calculated antenna potentials versus time for the antenna toroid radius R_{ant} of 30 cm at different toroid pipe radii. It can be seen from Fig. 7 that the antenna potential goes up as the above-ground height of the lightning decreases, i. e., as the lightning approaches the overhead line. With the lightning at some 50 m above ground, the antenna potential is about 100 kV, which exceeds the flashover voltage of a 0.7 m long creeping discharge (the distance between the electrode and the piercing clamp, see Fig. 1). At this voltage level creeping discharges start developing both sides of the electrode, which connect the grip to the piercing clamp. Fig. 7 also makes it clear that the antenna potential increases, although insignificantly, with the pipe radius owing to a growing capacitance between the lightning channel and the antenna. For the same reason the antenna potential grows with the toroid radius; this appears to be optimum at 30 cm.

The 100 kV antenna potential is attained even at the most unfavourable combination of various factors, such as a 5 kA minimum lightning current I_l , a 75 m distance between the lightning stroke point and the tower, and a low 1 Mohm leakage impedance. The antenna

potential increases with a heavier lightning current, a larger leakage impedance, a smaller stroke-tower distance, so the quoted estimates can be considered to have a certain safety margin.

Fig. 8 presents a pilot commercial 35 kV CCL, which was built in Komi Republic (North of Russia) for power supply of an oil field. The line is 60 km length and passes through forest and uninhabited region. In order to decrease maintenance cost the line three layers covered conductor was used, which insures reliable operation of the line even in case of a tree fall on the conductors. Lightning protection system for the line by LFA-A was used. At uppermost phase a toroid antenna can be seen.

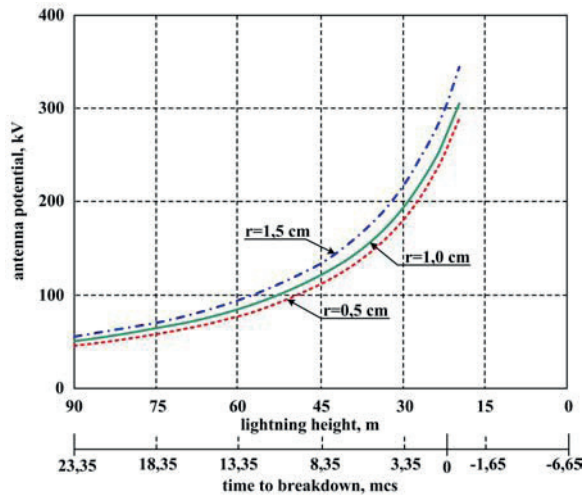


Fig. 7. Antenna potential vs. time to breakdown of the gap between the lightning and the line and vs. lightning height above ground at the toroid radius $R_{top}=30$ cm and different pipe radii r

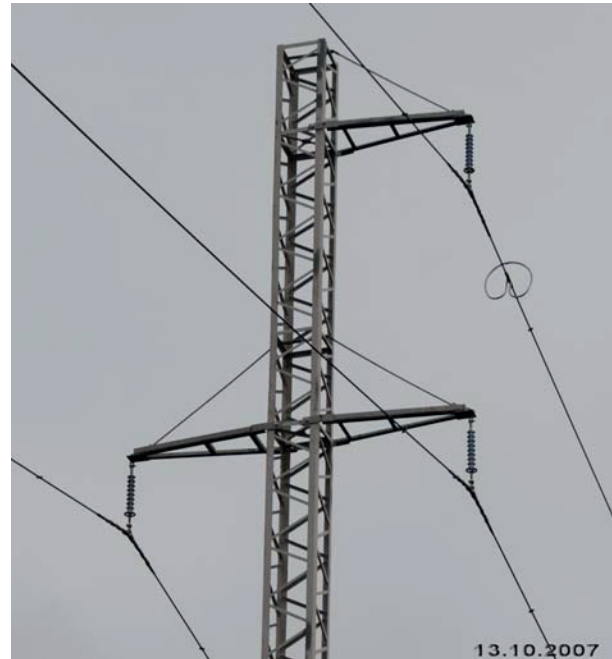


Fig. 8. 35 kV covered-conductor overhead line with Long Flashover Arresters of Antenna type.

7. CONCLUSIONS

1. A simple and effective method for lightning protection of power overhead distribution lines by long flashover arresters (LFAs) is presented. Even large lightning currents do not pose any threat to these arresters because the discharge develops in the air and not inside the device.
2. LFAs, which are based on the creeping discharge effect, increase the lightning flashover length significantly and thus eliminate Power Arc Follow (PAF). To protect a line against induced overvoltages, a single arrester should be mounted on a pole. To protect a line against direct lightning strokes, LFA-M arresters should be mounted in parallel with each insulator.
3. Lightning protection of a 35 kV overhead line with three-layers covered conductors can be feasibly implemented with the help of antenna-type long flashover arresters LFA-A. To this end, tangent towers of a covered-conductor line should be fitted with: 1) toroid-shaped antennas on the uppermost phase (one per tower) and 2) piercing clamps (two per phase, viz. six per tower). Conductors are suspended with the help of special supporting clamps with protectors assuring integrity of the covered conductors' insulation.

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