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ON THE NEED TO INCREASE THE RELIABILITY OF LINEAR INSULATORS FOR DISTRIBUTION NETWORKS 10-20 KV

***Introduction.** In Ukraine high voltage overhead distribution lines (OL) of class 6 and 10 kV are the most extended. Their total length exceeds 280,000 km. More than 95 % of the lines are made on line supports from reinforced concrete racks. On all poles of the overhead line, pin insulators are installed. According to the data of operation experience, up to 60-70 % of single-phase earth (SPE) faults due to «insulation» occurs on VL supports due to damage to line pin insulators, mainly during the thunderstorm period. **Problem.** Insufficient reliability of pin insulators leads to interruptions in power supply, accidents on the line, accidents in the area of reinforced concrete poles, where in the case of insulator damages, a long process of SPE occurs. **Goal.** The purpose of the work is to select the design and develop requirements for new linear insulators of 10-20 kV overhead lines that provide high resistance to lightning overvoltages with direct and inductive effects of lightning. **Methodology.** The research methodology consists in analyzing operational experience, calculating insulator parameters and laboratory tests. **Results.** Using statistical data on lightning parameters and data on mechanical loads on insulators, the main dimensions of line post insulators have been determined that will ensure their reliable operation under conditions of intense thunderstorm activity and extreme ice and wind loads. **Conclusions.** The main technical requirements for line post insulators for 10-20 kV distribution lines were formulated. On the 10 kV OL located in areas with increased thunderstorm activity it is recommended to use line post insulators instead of pin-type ones. On the OL-20 kV it is recommended to use only line post insulators. The use of high-lightning-resistant line post insulators on OL-10-20 kV will significantly increase the electrical safety and reliability of power supply to consumers. Increased by 2-3 times the cost of line post insulators in comparison with those used will be compensated for by the effects of reducing the number of collapsible supports, damage from under-supply of electricity, labor costs during transportation and restoration of destroyed supports, the moral side of reducing accidents in case of electric shock in the emergency zone. The insulators offered for OL-10-20 kV can be used for fixing both bare and protected wires. The exclusion from the design of the weakest elements – polyethylene caps and metal pins will increase the reliability of the power isolation unit.* References 11, tables 2, figures 1.

Key words: **overhead power line, pin insulators, line post insulators, lightning over voltages, electrical breakdown, flashover of insulator, power supply interruptions, electrical safety, reliability.**

Статья посвящена выбору конструкций и разработке требований к новым линейным изоляторам для распределительных сетей 6-10-20 кВ, обеспечивающих высокую устойчивость воздушных сетей к грозовым перенапряжениям при прямых и индуцированных воздействиях молнии. Повышение грозостойкости изоляторов позволит сократить перерывы в электроснабжении потребителей и уменьшить электротравматизм персонала электрических сетей при восстановительных работах. Библ. 11, табл. 2, рис. 1.

Ключевые слова: **воздушная линия электропередачи, штыревые изоляторы, опорно-стержневые изоляторы, грозовые перенапряжения, электрический пробой, перекрытия изоляторов, перерывы электроснабжения, электробезопасность, надёжность.**

Introduction. In Ukraine, overhead transmission lines (OL) of voltage class 6 and 10 kV are the most extended. Their total length exceeds 280,000 km. More than 95 % of the OL is made on supports from reinforced concrete racks. On all supports of the OL, pin porcelain ШФ or glass ШС insulators are installed. Pin insulators comply with IEC recommendations and current Standards requirements, but are damaged during OL operation. According to [1] up to 60-70 % of single-phase earth faults (SPE) due to «insulation» occurs on OL supports due to damage of linear pin insulators, the remaining 30-40 % – due to the destruction of arresters, insulation damage on transformer substations, etc.

The overwhelming majority of 6, 10 kV electric networks are made on supports of reinforced concrete racks made of vibrating reinforced concrete, with fastening of wires with the help of pin porcelain or glass insulators. In these solutions, the inadequate resource and low reliability of OL-6-10 kV are implemented. In 35 % of cases, accidents occurred due to the destruction and electrical breakdown of the pin insulators in the power unit.

At a direct lightning strike into the wire (DLS), when the overvoltage wave steepness exceeds 1600 kV/μs, a capillary breakdown occurs in the insulator head [2, 3], and at induced overvoltages from nearby lightning strikes (IO), insulators overlaps take place[4]. In both cases, under certain conditions, a spark lightning strike can go into an arc, supported by the operating voltage. From the thermal action of the arc, the insulator head is usually broken/scattered. A single-phase short-circuit (SPSC) mode occurs [5, 6].

The SPSC mode on a OL-6-10 kV line can exist without switching off the OL line from 2 to 6 or more hours. At the same time, a capacitive current of 5-10 A flows through the reinforced concrete support, and caverns burn out in concrete, reinforcing steel begins to melt, the greatest destruction of concrete and reinforcement occurs at the site of penetration of the support in the ground. Destruction of concrete and reinforcement leads to an unexpected fall of supports, and because of the flow of capacitive current near the support, life-threatening touch voltages and step voltage appear when approaching the human to the support [7].

In the letters of the «State Mining and Industrial Supervision of Ukraine» No. 4824/0/41-8/6/13 and No. 2071/0/4.1-9.1/-6/14 the following is indicated: «*According to the analysis of occupational injuries in the energy sector in 2013, 171 people were injured, including*

20 – with a fatal outcome. The main types of events during which accidents with a fatal outcome were: electric shock and falling victim with altitude along with the support».

The SPSC mode also affects the isolation of other electrical equipment. This situation in the Ukrainian 6, 10 kV networks should be corrected.

The goal of the work is choice of design and development of requirements for new linear insulators of OL-10-20 kV providing high resistance to lightning overvoltages at direct and inductive effects of lightning.

Main research materials. In countries where the transition to reinforced concrete supports was accompanied by the use of support-rod insulators instead of pin insulators, such problems did not exist. In Russia and Belarus to improve the reliability of distribution networks 6, 10 kV in 2004-2009 they began to develop and install support-rod insulators (porcelain and polymer) for the replacement of the pin ones [8].

The cardinal solution of the problem of reducing the accident rate of OL-10-20 kV in Ukraine will be installation instead of pin insulators of support-rod insulators (porcelain and /or polymer). Their design is shown in Fig. 1. Taking into account ongoing developments of the application in Ukrainian distribution networks of 20 kV voltage, insulators with voltage of 20 kV are also included in the work program.

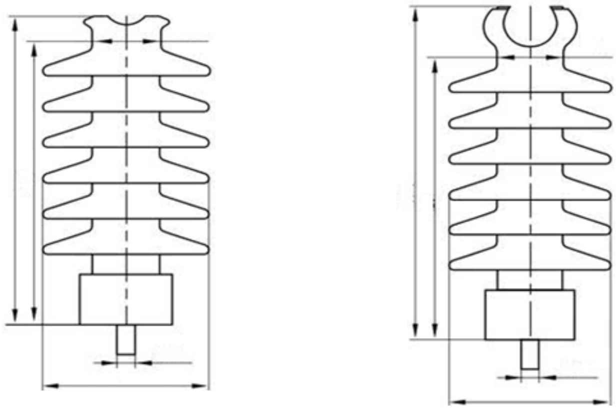

Fig. 1. Sketch of a support-rod insulator for OL 10-20 kV, options A and B

An even more effective solution would be the use of insulating traverses. The use of the traverses will greatly improve the impulse electrical strength, the moisture discharge voltage of the insulation and reduce the probability of lightning transfer to arc.

By improving these indicators, it is possible to reduce the specific number of switching off on the OL-6-10 kV by at least 7.6 times (Table 1).

For dead-end and non-ringed lines, the installation of support-rod insulators or traverses is practically the only cheapest way to solve the problem of unexpected power outage to consumers and reduce electro-injury and death of people. In Ukraine, support-rod insulators for OL-6-10 kV are not produced.

In this regard, the Research and Design Center for Development of the IPS of Ukraine, together with the PSC «Slavyansk High Voltage Insulators Works», at a meeting on September 25, 2017, considered the technical side of the development and production of reliable designs of support-rod insulators and traverses for OL-10 kV and OL-20 kV. The issue of the development of insulators and traverses in 2 versions – polymer and porcelain, suitable for use both on OL with insulated wires and on OL with protected wires was considered.

Table 1

Specific number of switching off of OL-6-10 kV, 1/100 km·100 thunderstorm hours in a non-forested zone (top estimation) [4]

Insulation	OL-6 kV		OL-10 kV	
	$N_{out..DLS}$	$N_{out.IO}$	$N_{out..DLS}$	$N_{out.IO}$
ШС-10А	13.0	11.0	17.3	21.1
ШС-10В	13.0	8.0	17.3	15.4
ШС-10Г	13.9	9.4	18.5	23.1
ШФ-10Г	12.2	8.8	16.2	19.7
ШФ-20В	11.4	3.7	15.2	8.4
ШК-10	11.8	8.8	15.7	18.6
ЛК 70/10	12.4	9.9	16.5	21.7
Insulating traverse ТИ	3.6	0.5	4.3	1.1
Note. DLS – direct lightning strike; IO – induced overvoltages.				

Particular attention was paid to the requirements for new insulators. Let us consider these issues.

Requirement for the normalized bending load. In the catalogs for pin insulators ШФ-10-20 kV and ШС-10-20 kV, the normalized mechanical force for bending F_{bend} = 12.5 kN is indicated. We explain the justification for the value of F_{bend} = 12.5 kN. This is important to understand when justifying the choice of F_{bend} for polymeric support-rod insulators.

The guaranteed fracture load in bending pins and hooks on all drafts does not exceed 3 kN and the crushing load on the support with three insulators – not more than 8 kN. Porcelain insulators with taking into account the possible heterogeneity of the raw material (clay, kaolin, sand), the conditions of firing, embrittlement and unpredictable aging were constructed with in advance inflated characteristics of strength to ensure the necessary (2-3 kN) bending strength during operation. In practice, a plastic cap applied between the pin and the porcelain insulator breaks at lower loads resulting from the bending pin: on the order of 1.5-2 kN load.

According to the conditions of the testing of pin porcelain insulators for mechanical loading, the insulator with a special high-strength rod (steel 40X, diameter at the base – 40 mm) is reinforced with a blind seal with cement-sand ligament. Only with a blind reinforcement with a special rod that does not bend under a load of 12.5 kN, tests can be carried out.

That is, in normal conditions, the «insulator – normal pin» assembly does not withstand more than 3 kN, so the use of insulators with a larger destructive load on the intermediate supports is economically inexpedient and can lead to the fall of the support itself, additional costs and time to rebuild the support. If the insulator breaks under load (for example, 4 kN) less than the strength of the support (8 kN), the power supply can be quickly restored by replacing the insulator. In this case, the wire in most cases does not fall to the ground, as it remains to hang on the broken insulator, if, of course, the load impact is terminated (for example, the fall of the tree was the cause of the accident) [9].

In projects for reinforced concrete supports, maximum drafts are provided in the following values: 2; 4; 6; 8 kN. Does a polymer insulator need for a load of 12.5 kN? Such an insulator will be quite expensive. We suppose that for mass application it is advisable to develop two types of insulator: for loads of 4 kN and 8 kN. They will fully ensure the reliability with the operating mechanical loads.

Requirements for lightning resistance. To satisfy the requirements for high lightning resistance, two conditions must be fulfilled:

1. Do not allow through-breakdown of the dielectric at direct lightning strikes into the wire.
2. Do not block the insulators with induced overvoltages with following transition of a spark discharge into the arc one.

Satisfaction of these requirements will make it possible to exclude hazardous modes of SPE in the overhead lines due to low lightning resistance of insulators.

To avoid breakdown, it is necessary to increase the thickness of the dielectric in the insulating part (piece) of the insulator, and to avoid overlapping – to increase the discharge distance over the surface (the distance between the metal parts by air). In both cases, the goal is achieved by increasing the insulating height of the support-bar insulator *h*.

The discharge distance ℓ_d for support insulators is determined by the known expression [10]:

$$U_{\text{imp.+}} = 670 \cdot \ell_d, \quad (1)$$

where $U_{\text{imp.+}}$ is the impacting the insulator impulse voltage from induced waves at lightning discharge (amplitude value), kV_{max}; ℓ_d is the discharge distance, m.

The amplitude values of the impulse overvoltages $U_{\text{imp.+}}$ are of statistical nature. The experimental laws for the distribution of amplitudes of induced overvoltages in 6-10 kV networks were studied in [4]. In this work it is shown that at the level of probability $P(U_{\text{DLS}}) < 0.08 \div 0.05$ the amplitude values $U_{\text{imp.+}}$ are 200-300 kV_{max}.

Substituting these values in the formula (1), we find that ℓ_d can be taken in the range of 300-570 mm. Taking into account the sufficiently low probability of overlap at such discharge distances ℓ_d, as well as the coefficient of transition of the impulse overlap into the arc of 0.5-0.7 [4], the dangerous situation in the line caused by the appearance of the SPE AT induced overvoltages will be minimized.

For support-rod insulators of 6-20 kV, the ratio of ℓ_d is approximately 1.2; so at ℓ_d=300-570 mm thickness of the insulating piece along the axis of the insulator will be 250-475 mm. With such thicknesses, the internal breakdown of insulators is unlikely, that is, the first condition of lightning resistance is also satisfied.

On the basis of the above explanations, the basic requirements for support-rod insulators for 10-20 kV overhead lines presented in Table 2 were formulated.

Table 2

The main technical requirements for support-rod insulators for OL-10-20 kV

Indicator name	Porcelain insulators		Polymeric insulators	
	10 kV	20 kV	10 kV	20 kV
Mechanical force for bending F_{bend}, kN	8	8	4	4
Discharge distance ℓ_d, mm	400	450	400	450
Lightning impulse test voltage, kV_{max}	280	300	280	300
Length of leakage current path (not less than), mm	700	700	700	700
Probability of overlapping with induced overvoltages $P(U_{\text{IO}})$, not more than	0.08	0.075	0.05	0.075

Conclusions.

1. The main technical requirements for support-rod linear insulators for 10-20 kV OL are formulated.
2. On OL 10 kV located in areas with increased thunderstorm activity, it is recommended to use linear support-rod insulators instead of pin-type ones. On OL-20 kV it is recommended to use only support-rod insulators.
3. The use of support-rod insulators of high lighting resistance on OL-10-20 kV will significantly increase the electrical safety and reliability of power supply of consumers.
4. The cost of support-rod insulators increased by 2-3 times in comparison with those used will be compensated for by the effects of reducing the number of collapsible supports, damage from under-supply of electricity, labor costs during transportation and restoration of destroyed supports, the moral side of reducing accidents in case of damage by electric current in the emergency zone.
5. The insulators offered for OL-10-20 kV can be used for fixing both bare and protected wires.
6. Exclusion from the design of the weakest elements – caps and pins will increase the reliability of the power insulation unit.

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