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The device for monitoring the LED display high-voltage insulators state

R N Balobanov, D K Zaripov and AA Akhmadeev

Department of Electric Stations, Kazan State Power Engineering University, Krasnoselskaya St., 51, Kazan, 420066, Russia

E-mail: rassel_ipek@mail.ru

Abstract. The article discusses the possibility of using devices for monitoring the state of high-voltage insulators with LED indication, mounted on insulating structures of high-voltage lines and substations. The scheme of the device is given and its principle of operation is described. The feasibility of indicating the early stage of the an insulation defect development in a laboratory and full-scale experiments on real power system facilities using devices with LED indication are shown. A new method of insulation control using the developed device will allow, when visually inspecting an overhead line, to additionally provide information about the change in the electric field and the appearance of discharges in the insulation. In addition to the early warning of the birth of a defect, this information will be useful for routine maintenance (cleaning) of insulators.

Keywords: polymer insulator, indicator, defects, LEDs, power line, insulation condition, assessment, outdoor switchgear, contactless method, dynistor.

1. Introduction

The object of study is high-voltage insulators. According to the brochure "The main results of the electric power facilities operation in 2016. The results of the 2016–2017 autumn-winter period (OZP), issued by the Ministry of Energy of the Russian Federation in 2017, the number of accidents that led to the cessation of electricity supply to consumers with a capacity of 10 MW or more due to the damage of overhead line insulators (OHL) amounted to 12% of total number of accidents with such damage on overhead transmission lines (HVTL), substations (PS) and open switchgear (ORU). If we consider only VL, then it is 22.6%. These indicators are inferior only to those due to extreme external influences and significantly exceed these indicators due to, for example, thunderstorms or ice [1]. The damage to insulators in most cases occurs as a result of aging, surface contamination, manufacturing defects and accidental damage during repairing work.

A special place among the types of damage to the overhead lines insulation is taken by the damage to the suspension polymer insulators associated with their breakdown or overlap. According to the Research Institute of Electric Power Industry (EPRI) in the USA, where the operating experience of polymer insulators on overhead lines is more than 30 years, over the past 10 years, the US electrical grid companies have begun to experience an increasing number of polymer insulators failures on transmission lines 115 and 138 kV. EPRI studies have shown that these failures are usually associated with high electric field strengths occurring near or on high-voltage insulators. The decrease of overhead lines reliability is due to the constant activity of electrical discharges on metal fittings. Constant impact on the insulation of these corona discharges leads to the formation of cracks in the polymer shell and destruction of the mechanical seal, therefore, constant monitoring of this type of insulators condition is necessary [2].

At present, radiowave [3-6], acoustic [7-10], optica [11-14] and thermal imaging [15-18] methods of insulator control are used in electric power industry. The use of these methods is convenient and effective in diagnosing the supporting and suspension insulators of substations, but it is difficult in examining extended objects such as overhead lines. Instrumental examination of overhead lines from aircraft also did not find wide application. Therefore, according to researchers, more than 40% of companies still use mostly visual inspection of equipment. Infrared diagnostics and night vision devices are used by approximately 15% of enterprises, and only a few enterprises use measurements of radio emission and ultrasound monitoring [19-20].

Remote control methods of isolators have not been able to supplant a simple visual inspection of overhead lines and are only an addition to it. At the same time, during visually inspecting polymer insulators, it is not always possible to identify defects, since in most cases they are not visible. Consequently, there is an actual scientific problem associated with the lack of effectiveness of the existing methods for controlling insulators of overhead lines. Its analysis revealed the need for the development and research of new methods for controlling insulation using devices installed on insulators, which would allow for visual inspection of overhead lines to signal their condition directly.

2. Materials and Methods

One of these devices is our proposed indicator. The scheme of the device is made on the basis of dynistors [21-24] figure 1. In Figure 1, the dotted lines indicate the connection of the indicator with the high-voltage and grounded part of the structure. A feature of this scheme is the ability to display discharges that occur in the insulation during damage and / or contamination. The circuit consists of two loops. The first one includes the following elements: capacitance C1, resistances R1 and R2, dinistor VD6 and green LED HL1. The second one consists of the capacitance C2, the resistance R3, the dynistor VD7 and the red LED HL2.

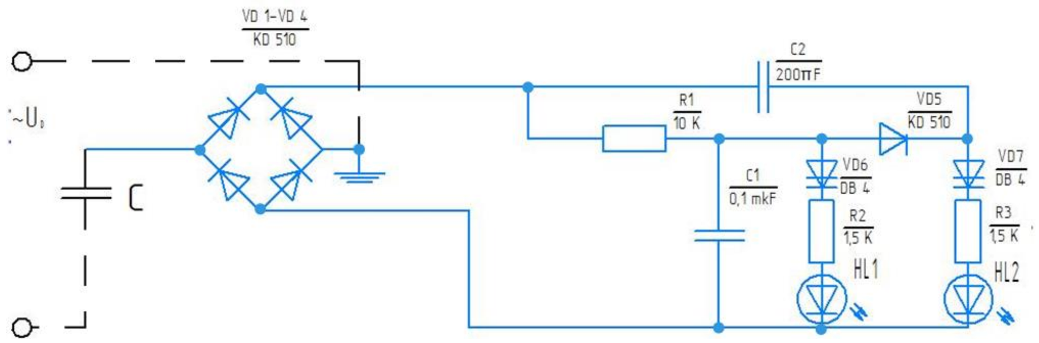


Figure1. Diagram based on dynistors

Let's consider the principle of the indicator. The distribution of potentials along an insulating structure changes in violation of the integrity of its individual parts. The potential difference in the damaged area decreases, which causes an increase in voltage on the intact part of the structure. The defective condition of the insulator can be detected, for example, by increasing the intensity or frequency of the pulses of the light emitted by the indicator mounted on the portion of the insulating part of the structure or support, as this increases the voltage on it. One of the electrodes of the radiator can be earthed through the grounded part of the insulator or support, the second electrode can be positioned freely [25-26].

To ensure reliable operation of the radiator with a constant installation, it is necessary to connect a discharger in parallel to it. In the event of a surge overvoltage, the discharger shunts the radiator, protecting it from failure.

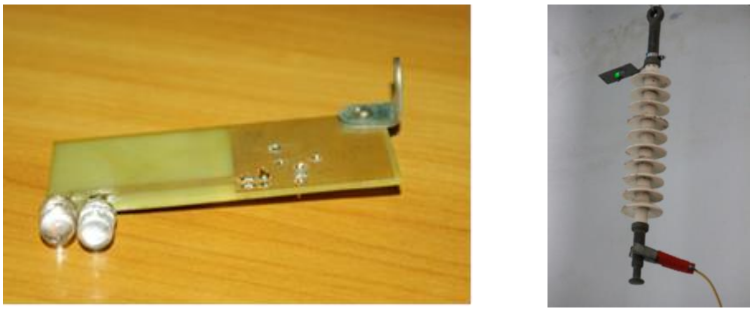
The scheme works as follows. The current from the diode bridge VD1-VD4 charges the capacitance C1. As charging C1 voltage on it increases. The dynistor VD6 does not pass the current until the voltage on its terminals (on C1) reaches 40 V.As soon as the voltage reaches the desired value, the dynistor opens and the charge from the capacitor C1 is discharged to the LED HL1, as a result of which the LED emits a flash of green light. Simultaneously with the flash, the voltage on the dynistor VD6 drops, and it closes. Next, the capacitance C1 is again charged until the opening voltage of the dynistor and the cycle repeats. Thus, the green LED is pulsed.

If there are no discharges on the insulation, only the green HL1 LED will always be triggered, because due to the voltage drop across the VD5 diode, the dynistor VD7 will always be closed.

At a certain intensity of the discharges on the insulator, the pulses, passing through the second (high-frequency) circuit with a capacitance C2, will increase the voltage on the VD7 dynistor to a level higher than that on the VD6 dynistor. Then VD7 will open first and the red LED HL2 will light up. The value of capacitance C2 is selected in such a way as to react to the appearance of short pulses (≤ 1 μs) caused by discharges on the insulator. More details ot the work of the LED indicator are considered in the thesis.

3. Results.

According to the scheme described above, experimental samples of the indicator were fabricated, which were tested in the high-voltage laboratory of Kazan State Power Engineering University and at existing OHL and open switchgear. The appearance of the indicator and the location on the insulator are shown in figure 2



a b

Figure 2. Appearance (a) and location on the insulator (b) variants of the LED indicator

The indicator developed according to this scheme is able to detect the following types of defects and damage to insulators:

1. Erosion of the shell and the formation of a track on the outer surface of the protective shell of the insulator figure 3. This defect may occur during the operation of insulators in areas with severe contamination due to the impact of surface discharges in wetted insulators.

Figure. 3. Erosion of the containment shell

Figure. 4. Breakdown of a linear polymer insulator on HVL 330 kV

2. Formation of dendrites in a fiberglass rod and tracks at the interface of the "core-shell" section in a polymer insulator figure 4.

Often this is accompanied by an internal erosion of the containment up to the formation of through holes. This damage is also associated with the penetration of moisture into the insulator. The root cause of damage is most often a defect in the design of the insulator, namely:

- insufficient tightness of the interface between the shell and metal reinforcement;
- poor adhesion of the shell to the fiberglass rod.

In addition, the leakage may be due to damage (breaks) of the shell during transportation of insulators or installation.

According to the operating experience, this type of damage to polymer insulators is the most common. The breakdown of the insulator is accompanied by the occurrence of an electric arc with the destruction of part of the protective sheath.

It is almost impossible to identify the location of the indicated damage while visually inspecting insulators on an overhead line because of the large distances to them and the need to choose an observation angle each time.

Similar defects were simulated in the laboratory. In the picture (Fig. 5), two polymer insulators LC 70/35 are shown, to which AC voltage was applied from 0 to 25 kV. One of the insulators (right) has a defect in the form of a longitudinal conducting channel that shunts a part of the structure (~ 30%), and the second (left) is serviceable. LED indicators are attached to the upper electrodes of both insulators.

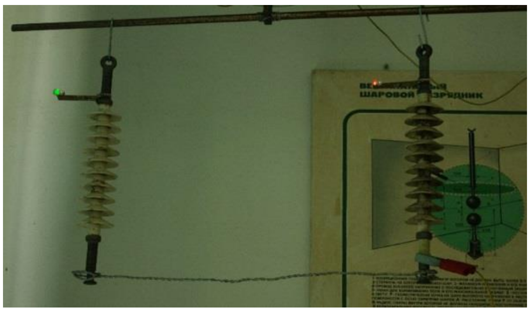


Figure. 5. Image of defective and serviceable polymer insulators with LED indicators mounted on them

For the experimental part of the work, an electrical circuit was assembled (Fig. 6), designed to measure the leakage currents of the insulator, as well as the parameters of the LED indicator of the defect.

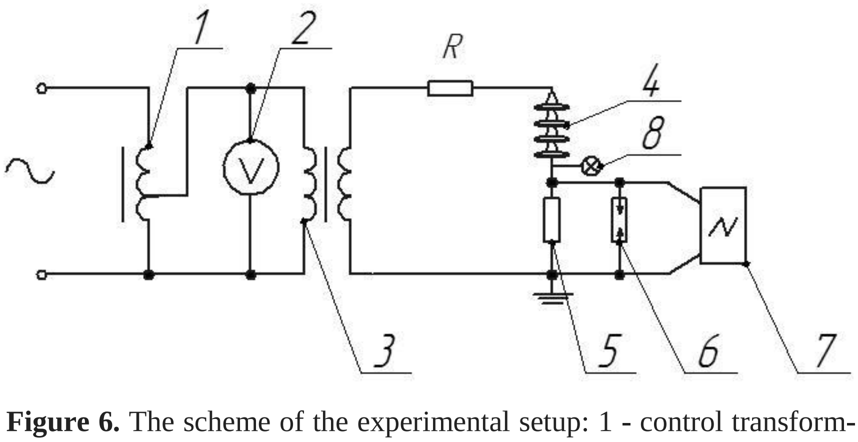


Figure 6. The scheme of the experimental setup: 1 - control transformer; 2 - voltmeter; 3 - test transformer; 4 - the test isolator; 5 - resistance (r = 1 kΩ); 6 - discharger; 7 - oscilloscope; 8 - LED indicator

The source of voltage of industrial frequency is the test transformer IOM - 110 kV (3). The voltage on it is regulated by the autotransformer RNO-10/250 (1). Resistor R is used to protect the transformer from large currents and a large slope of the voltage at the overlap of the test insulator (4). The measuring circuit consists of a resistor r = 1 kΩ (5), a spark gap (6), designed to protect the oscilloscope (7) in the event of an overvoltage.

4. Discussion.

The experiments were carried out on suspension polymer insulators brand LK 70/35 for voltage of 35 kV. A working voltage of 20 kV was applied to an insulator of brand LK 70/35, and a defect was artificially created by short-circuiting an insulator from 0 to 50%. The dependence of the pulse repetition rate of the green LED on the degree of damage to the insulator Fv = f (n) was determined. The results of the experiment are listed in Table 1 and displayed on the graphs (Fig. 7)

Table 1 The results of experiment No.

U, кВ	20	20	20	20	20	20
The proportion of defect in the insulator*n*, %	0	10	20	30	40	50
LED pulse repetition rateF_v, 1/c	1,23	1,42	1,69	1,88	-	-
$K(n)=F_v(n)/F_v(0)$	1	1,15	1,37	1,52	-	-
LED color*	G	G	G	G	R	R

*G- green; R-red

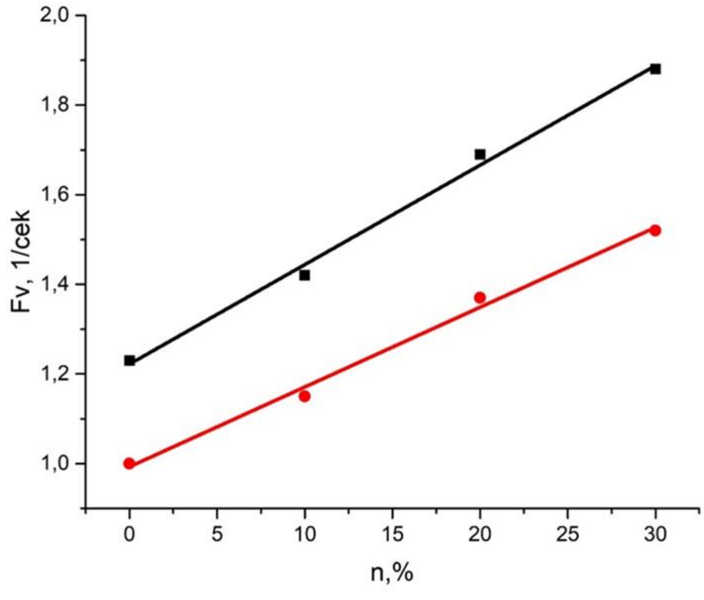


Figure 7. Dependences K (n) and Fv (n) on a damaged insulator LC 70/35

An analysis of the graphs of K (n) and Fv (n) (see figure7) and the data in Table 1 allows us to conclude that when a defect develops on an insulator of the brand LK 70/35 along the length up to 30% of the insulating distance, there is an increase in the repetition rate pulses of green LED indicator. With an increase in the length of the defect up to 40% of the insulation distance and the red LED lights up more.

When the voltage was raised, it was clearly observed on the one hand, the increase in the pulse repetition rate of both indicators, and on the other, the pulse repetition rate on the defective insulator was

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noticeably higher. When a voltage of 20 kV was reached, pulses of a red LED appeared on the indicator mounted on the defective insulator. On a good insulator, the green LED pulses continued.

The results obtained in the laboratory, allowed to go to full-scale experiments on real objects of the power system. The tests of the indicators took place in the 110 kV outdoor switchgear of the Kazan CHP-3 (OJSC TGK-16). The defect indicator was mounted on an insulating rod and was brought into contact with a grounded part of the supporting insulators by a single electrode (Fig. 8). On the inspected support insulators, as can be seen in Figure 9, the indicator glow was sufficiently bright for visual detection in sunlight.

Figure 8. Order of work

Figure 9. Defect indicator at the support insulator in the open switchgear 110 kV

As a result of the survey conducted on 07/11/2017, the 110 kV outdoor switchgear of Kazan CHP-3 using an LED indicator of high-voltage insulation attached to an isolation rod, insulators were found, on which increased intensity of discharges was observed (red indicators glowed): cell 1 reference insulators of phase A , B, C; cell 2 is a phase A supporting insulator; cell 4, phase A supporting insulator;cell 6 supporting insulators of phase A, B, C; cell 7 supporting insulators of phase A, B, C; cell 8 supporting insulators of phase A, B, C; cell 10 supporting insulators of phase A, B, C; cell 11 supporting insulator phase C; cell 14 is a phase C supporting insulator, cell 17 is a phase A, B, C reference insulators; cell 18, phase A, B, C reference insulators. This assumption was confirmed by partial discharges fixed on the surface of these insulators by the UD-8V ultrasonic flaw detector.

The likely reason for the increased intensity of discharges is the non-standard mounting of the flexible bus to the insulator using a standard corner, as well as the pollution of the insulators.

It was recommended to replace the corners with standard clips and to maintain the insulators.

The experimental work was continued in Almetyevsk electrical networks of JSC "Grid Company". During the experiments, about 50 defect indicators were installed on 35 kV and 110 kV lines.

The purpose of the work in Almetyevsk electrical networks, where the indicators were introduced, is to study the possibility of large-scale use of indicators to monitor the condition of overhead polymer insulation of overhead lines, as well as the possibility of excluding from the regulations periodic monitoring using thermal imagers and electron-optical flaw detectors.

The prototypes of the indicators worked on the 35 and 110 kV lines for more than six months and showed good reliability. Of the 39 pieces of checked bypass indicators after six months of operation did not work 5 pieces.

As for the performance of indicators according to their intended purpose, today only about 50 indicators have been installed on the lines and it is still too early to carry out a full-scale assessment of the effectiveness.However, when going round together with the head of the VL service of a section of the 110 kV line "Abdrakhmanovo-Uzlovaya" with indicators installed on all phases on the polymer insulators of the individual phases of the three pillars, an increased blinking of the green LED was detected. This anomaly was taken by the VL service under control. The indicator operation on the 35 kV "Wastewater treatment plant - Substation 126" line is shown in figure 10.

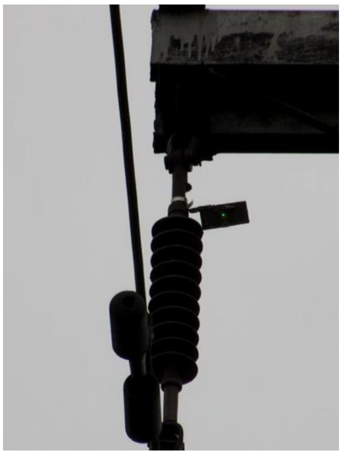

Figure 10. Indicator operation on the 35 kV "Wastewater treatment plant - Substation 126" line

The ability to use indicators on various types of insulators and voltage classes. One of the main advantages of the developed indicator is its versatility.As laboratory and field experiments have shown, it can be used without any changes in the design on various types of insulators and on various classes of voltages, both on high-voltage lines and on the open switchgear.The indicators were tested and tested on garlands of suspended glass insulators, suspended polymer insulators of 35 and 110 kV lines. The same indicators installed on the isolation rod were inspected on the open switchgear, supporting porcelain and polymer insulators with a voltage of 110-220 kV. We consider the most promising use of indicators to control polymer insulators of voltage class from 35 kV to 500 kV. However, additional evidence is needed to confirm this finding.

5. Conclusion.

A device for monitoring the state of high-voltage insulators (LED) on power lines and switchgears, based on the registration of changes in the electric field in the area of the insulator when a defect appears, was developed.

The developed LED indicator of the state of high-voltage insulation does not require an autonomous power source and allows to record both the breakdowns of the insulator part and the occurrence of electrical discharges on it.

Laboratory and field experiments showed the possibility of using the developed indicator to monitor the insulation status of suspension and support insulation of overhead lines and open switchgear.

Indicators can be used as stationary devices mounted directly on the insulator, and as a portable device mounted on an insulating rod.

These indicators will help the electrical network personnel to assess the condition of the insulators during planned inspections of the switchyard.

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