Innovative insulation coating of the high-voltage line to reduce the corona effect

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Abstract. The paper discusses a method for reducing electricity losses on high-voltage power lines through the use of a new insulating coating, the action of which is based on the effect of the "blocking layer". The study of samples of free-flowing and flexible dielectric regarding the possibility of implementing the proposed coating is presented. Possible combinations of materials for covering power lines wires are analysed, as well as the results of computer modelling and experimental verification of the statements under consideration. Based on the static data of experimental studies, the results of computer modelling and theoretical assumptions, empirical dependences of the volt-ampere characteristics of the reverse corona in the studied samples were obtained.

1 Introduction

Corona around the wire and linear fittings are frequent phenomenon on high-voltage power transmission lines [1]. Such effect occurs due to the coincidence of various factors and as a result leads to the loss of energy from the grid. It is possible to eliminate this phenomenon as follows: by using wires of a certain configuration and cross-section, splitting of wires, coating the wire with a dielectric coating. The latter is able to eliminate the critical electric field strength on the surface of the conductive wire at which the corona effect occurs, just under certain conditions [2]. The value of the maximum tension on the surface of the dielectric coating of the wire will be determined by the thickness and combination of materials used in the selected insulation. Comparing the characteristics of reducing electric field strength when moving away from the uninsulated and insulated wires, one can notice their coincidence and difference only in the value of the maximum electric field strength, but at the same time, it is impossible to achieve complete elimination of electric field strength.

On the other hand, the elimination of the corona effect of high-voltage power transmission lines wires will reduce power losses, eliminate radio interference, acoustic noise and increase the service life of the line by reducing wire corrosion resulting from electrical discharges [3].

The causes of the corona on the wires are bad weather conditions, defects in the wires of the power transmission line, overvoltage, a small distance between the phase wire and the grounded element, that can happen because of an accident or swaying wires [2].

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Ideal weather conditions, absence of defects on the line wire and placing two wires with phase F1 and zero N at a distance l from each other (Fig. 1) will create a distributed value of the strength E around the phase wire at a distance r according to a sinusoidal characteristic (Fig. 2).

![Fig. 1. Design model.](image)

Point A (Fig. 2), indicating the maximum value on the characteristic of the electric field strength distribution, is located on the line of the smallest distance between the wires F1 and N (Fig. 1).

![Fig. 2. Electric field strength distribution around the F1 wire at a distance r.](image)

The increase in electric field strength at point A around the phase wire is characterized by the proximity of the neutral wire, where air ionization and a directional current flow occur. It is possible to counteract this with the help of a dielectric \[\] preferably not conducting an electric current, exceeding the critical voltage, however it is currently impossible due to the lack of such a material, and existing materials, as mentioned above, only reduce the value of the maximum electric field strength.

At the same time, the electric field strength can be reduced by creating a second field along the wire perimeter with the opposite direction of the field strength. In this case, the charges will interact according to the principle of superposition. A similar effect is observed in electrostatic precipitator designed to capture fine particles from the purified flue streams, and is called the reverse corona [5]. In the electrostatic precipitator, this phenomenon is negative, as reduction of the field strength in the active zone of the electrostatic precipitator worsens the efficiency of its operation [6]. However, the use of this effect on power lines, on the contrary, will be a positive factor that allows to reduce losses.

Analyzing electricity losses on the power lines, one can notice their variability throughout the year [2]. The change in percentage indicators is characterized by the influence of the weather conditions in the form of air humidity, precipitation, atmospheric pressure and temperature on the process of occurrence of the corona effect. The amount of electricity losses due to corona on high-voltage power lines, according to various sources, ranges from 17 to 35% [1].
As mentioned above and confirmed by the results of modeling, as well as instrumental studies, the use of insulation on conductive lines can only reduce the resulting field strength and that is not effective in case of voltage surges and some emergency [7]. The use of an insulating coating with a blocking effect in the layer will reduce both the operating field strength and its increased value in emergency situations or worsening weather conditions by enhancing the blocking effect.

2 Line loss reduction methods

The essence of the phenomenon of the formation of the blocking layer of the "reverse crown" is that with high electrical resistance and polarization of the layer of the substance with which the wire is covered, the conductivity of the layer turns out to be small, which increases the voltage drop in the layer and reduces its drop in the air gap, characterized by a distance, "for example," to the grounded part of the support. With an overall high potential difference, the substance is recharged from a negative to a positive sign and the release of reverse ions (positive, instead of negative) occurs in the air gap.

The presence of an inverse corona in the layer is experimentally determined by the volt-ampere characteristic (VAC) [8]. Depending on the type of a substance, three types of inverse corona are determined, which have a different effect on the resulting electric field strength. For some energy systems, this effect is a negative factor that reduces their performance, however the use of this physical feature in an insulating coating capable of recreating the blocking action in a limited layer will significantly reduce the level of field strength that occurs around the wire of a high-voltage line, compared with a classical dielectric coating.

At this stage of the study, soot and coal that are mainly necessary for studying the process of the formation of the reverse corona were considered as a catalyst for the insulating layer [9].

The active resistance of the studied free-flowing samples in this case will depend on the density of the substance and its composition. For example, a layer of soot obtained by burning wood fuel changes the active resistance as this layer is compacted Fig. 3.

![Fig. 3. The resistance of the carbon black layer depending on the density.](image)

The influence of a number of dielectric materials, silicone (sample No. 1), and samples with catalysts (sample No. 2), (sample No. 3) was also evaluated. Silicone was used as the basis for the catalysts due to its accessibility, plasticity and easy processing. The study was carried out on rectangular plate samples 100x100 mm and with a thickness of 4 mm.
One of the indirect indicators of the proposed insulation layer is the discrepancy between the ascending and descending characteristics of the field (VAC and the dependence of the corona current, mA, on voltage, kV) [4]. Figure 4 shows the VAC during the formation of the reverse corona in coal dust. According to [7], this layer is characterized by a stable reverse corona. The process of forming the reverse corona is described quite sufficiently in a number of works [10-11].

By analogy with the resistance of bulk samples (Fig. 3), and their concentration in the studied samples will affect the remaining parameters. Sample 3, having a 20% content of this substance, shows a weak inverse corona effect. An increase in the percentage of soot in the silicone layer should increase the effect of reverse crowning, however, it will lead to a decrease in the plasticity of the layer.

Fig. 4. Volt-ampere characteristic of the inverse corona in a layer of coal dust.

3 Results of studies of insulating coatings of the line

Figure 5 shows the VAC obtained in the study of rectangular plate samples with catalysts No. 1 – 3.

Fig. 5. Volt-ampere characteristic in the layer.
As the results of experimental studies of sample No. 1 show, the behavior of silicone insulation in an electric field with high strength is characterized by dielectric parameters without the formation of a reverse corona. Samples No. 3 and No. 4, on the contrary, confirm the presence of a reverse corona in this layer, but with different efficiency.

Thus, we can say that by applying a semiconductor polymer coating with a high electrical resistance to the wire, is able to create local corona points on its surface, which, as a result of polarization, throw ions of the opposite sign towards the wire, as a result of which an electric field with an uneven distribution of tension arises around the wire (Fig. 6). This effect occurs and increases as a result of an increase in the field strength at the surface of the current-carrying core as a result of the factors described above.

![Fig. 6. Volt-ampere characteristic in the layer.](image1)

The difference between this method of reducing the voltage $E$ on the power line wires, compared with the application of a simple insulating coating, is that the value of the resulting field strength outside this coating is significantly different from the simple reduction of the voltage of both the wire with insulation and without it (Fig. 7).

![Fig. 7. Characteristics of the field strength distribution.](image2)
When local points of the reverse corona occur along the perimeter of the polymer coating (Fig. 8), the distribution of electric field strength around the wire at a distance r will already be represented by a characteristic that differs sinusoidal (Fig. 2) in both shape and magnitude.

Fig. 8. Distribution of electric field strength around the wire with a point inverse corona.

4 Conclusions

Regardless of the dielectric type, when an electric field occurs, an electric current will pass through the dielectric, as a result of which it will be heated. Heating the insulation in this case will counteract the formation of ice on its surface. This effect can act as an additional positive factor when considering the problem of ice formation on power transmission lines. With the classical methods of dealing with ice [12], mostly by heating the wires and melting ice accumulated on them, the existing insulation of the wire will act as a heater, which will lead to less thermal losses when the wire is warmed up, and in combination with heating the dielectric coating due to the leakage currents that occur in this process will lead to energy savings spent on this process.

The increase in wind load on a wire with a dielectric coating 4 mm thick will vary in the range of 12-14% for a 110 kV power transmission line wire, this percentage will be less for the lines with high voltage [13]. For example, the magnitude of the wind load during the formation of ice can reach 300%.

In addition to the advantages discussed above, the polymer insulating shell of the power transmission line is able to prevent a short-term short circuit resulting from the swinging - "dancing" - of the wires. Moreover, in case of a line break this insulation is able to prevent voltage spreading along the ground, which is already part of electrical safety to reduce the step voltage [14-15].

Potential for use of this technical proposal on power transmission lines is characterized by its efficiency, which proceeds from this paper, with minor consequences in the form of increased windage, that in case with power transmission lines with voltages below 110 kV will have an additional positive effect in the fight against ice formation.

This work can be useful in the design of new transmission lines and the modernization of existing sections of transmission lines in order to reduce losses and increase the efficiency of electricity transmission.
References

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