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DISCHARGE VOLTAGE UNDER HUMID CONDITIONS

Abstract. *The paper examines the issue of the relevance of the implementation of underground substations in the current conditions of Ukraine. The need for such research was proven, and the direction of research in this broad topic was also established. It is noted that the mechanisms of the insulator overlap during rain and when the surface is contaminated and moistened are similar. It has been proven that under the action of voltage applied to the insulator, a leakage current passes through the moistened layer of pollution, which heats it up. Since impurities are distributed unevenly on the surface of the insulator, and the density of the leakage current is not the same in individual sections of the insulator due to the complex configuration of its surface, the heating of the contamination layer also occurs unevenly. In those areas of the insulator where the current density is the highest, intensive evaporation of water occurs and dried areas with increased resistance are formed. The voltage distribution on the surface of the insulator changes. Almost all the loads affecting the insulation fall on dry areas. As a result, dry areas are covered with The need to create recommendations for the use of insulators in conditions of an underground substation (high humidity and pollution) has been established. The methods of calculating the necessary parameters were considered and norms were established, which need to be updated for the operating conditions caused by underground placement.*
Keywords*: insulator overlap, leakage current, influence of contamination, air humidity, partial discharges*

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ВОЛОГОРОЗРЯДНА НАПРУГА ІЗОЛЯТОРІВ В УМОВАХ ПІДЗЕМНОЇ ПІДСТАНЦІЇ

Анотація. *В роботі розглянуто питання актуальності впровадження підземних підстанцій в поточних умовах України. Була доведена необхідність подібних досліджень, а також встановлено напрям дослідження в цій широкій темі. Зазначено,що механізми перекриття ізолятора під час дощу та при забрудненні та зволоженні поверхні схожі. Доведено, що під дією поданої на ізолятор напруги через зволожений шар забруднення проходить струм витоку, який нагріває його. Оскільки забруднення розподіляються по поверхні ізолятора нерівномірно, а щільність струму витоку неоднакова на окремих ділянках ізолятора через складну конфігурацію його поверхні, нагрів шару забруднення також відбувається нерівномірно. У тих ділянках ізолятора, де густина струму найбільша, відбувається інтенсивне випаровування води і утворюються висушені ділянки з підвищеним опором. Змінюється розподіл напруги на поверхні ізолятора. Майже всі навантаження, що впливають на ізоляцію, припадають на висохлі ділянки. В результаті висохлі ділянки покриваються іскровими каналами, які називаються частковими дугами. Опір іскрового каналу менше опору висушеної ділянки поверхні ізолятора, тому струм витоку збільшується. Збільшення струму витоку призводить до подальшого висихання шару забруднення, а отже, до збільшення його опору. Встановлена необхідність створення рекомендацій до використання ізоляторів в умовах підземної підстанції (високої вологості та забрудненості). Розглянуто методи розрахунку необхідних параметрів та встановлено норми, які потребують актуалізації для умов експлуатації, зумовлених підземним розміщенням.*
Ключові слова*: перекриття ізолятору, струм витоку, вплив забрудненості, вологість повітря, часткові розряди.*

Introduction. The energy strategy of Ukraine, although not officially, has undergone some changes. Due to enemy attacks on electric power facilities with long-range weapons, the country took a course to create safe conditions for key electric power facilities. Thus, there was a demand for the design and implementation of underground substations and power transmission lines in the country. Thus, one of the important theoretical problems is the formation of norms and rules for the arrangement of such electric power facilities, because the conditions underground are significantly different from those on the surface and have several features that need to be paid special attention to.

Summary of the main part. The world already knows similar solutions, for example: an underground high-voltage substation in Singapore, consisting of 4 underground floors where all the main equipment is located, and has 5 above-ground floors where the customer's head office is built, an underground substation in Anaheim, California, USA is located under by Theodore Roosevelt City Park, one of the largest underground substations in the world at 500 kV is located in the center of Shin Toyosu , Tokyo, where the substation consists of 5 floors and only one above ground. However, they were not widely distributed among other countries, since they did not find themselves in such a difficult situation as Ukraine. Among the critics of this approach, low throughput was noted , but we have already considered and described this issue in [1] . Also, the demand of the country itself has already been confirmed by the availability of government orders for project development methodology. This gives us every reason to say that such an approach takes place and, with the correct formulation of the main recommendations for implementation, can surpass standard power transmission lines in terms of basic parameters. Therefore, the relevance of the issue is beyond doubt and confirms the need for development in this direction [2].

Therefore, the main goal of our research is to find optimal solutions for creating underground substations and the most efficient configurations. One of the issues that needs to be investigated is wet-discharge voltage and the overlap of insulators due to contamination.

During operation, the surfaces of the insulators are always contaminated. As a rule, dry contaminants that have a high resistance and do not affect the voltage distribution on the surface of the insulator do not significantly reduce its discharge voltage. The wetting of the pollution layer by drizzling rain or dew leads to a decrease in the resistance of the pollution layer, a change in the voltage distribution on the surface of the insulator and, as a result, to a decrease in its discharge voltage.

The mechanisms of the insulator overlap in the rain and when the surface is contaminated and moistened are similar. Consider the development of a discharge in the case when the surface of the insulator is contaminated and moistened.

Under the action of the voltage applied to the insulator, a leakage current passes through the moistened layer of contamination, which heats it up. Since contamination is unevenly distributed over the surface of the insulator and the leakage current density is not the same in individual sections of the insulator due to the complex configuration of its surface, the heating of the contamination layer also occurs unevenly. In those areas of the insulator where the current density is the highest, intensive evaporation of water occurs and dried areas with increased resistance are formed. The voltage distribution on the surface of the insulator changes. Almost all the stress affecting the insulation is applied to the dried areas.

As a result, the dried areas are covered by spark channels, which are called partial arcs. The resistance of the spark channel is lower than the resistance of the dried section of the insulator surface, so the leakage current increases. An increase in the leakage current leads to further drying of the pollution layer, and therefore to an increase in its resistance.

Intensive drying of the surface of the insulator at the end of the arcs leads to their elongation. Drying of the entire surface leads to a decrease in leakage current, and an increase in the length of partial arcs leads to its growth. If the result is a decrease in the leakage current, then the arcs will extinguish, if the leakage current increases, then the partial arcs will lengthen and cover the entire insulator. Since the parameters of the partial arc and the number of arcs simultaneously existing on the surface of the insulator are random, the overlap is also a random event characterized by a certain probability. The probability of an insulator overlap increases with increasing exposure to voltage, because at the same time the leakage current increases, which contributes to the extension of partial arcs until the insulator is completely overlapped.

From the given picture of the development of the discharge, it follows that the discharge voltages of the insulators will be the higher the lower the leakage current [3-5]:

$$I_y = \frac{U}{R_y} \tag{1}$$

where I_y is the leakage current; R_y– leakage resistance on the surface of the insulator.

If the pollution layer has a thickness with specific volume resistance, then for a smooth cylindrical insulator with a diameter D

$$R_y = \frac{\rho \cdot L_y}{\pi \cdot \Delta \cdot D} \tag{2}$$

where L_y is the length of the leakage path.

From formulas (1) and (2) that:

$$I_y = \frac{U \cdot \pi \cdot \Delta \cdot D}{\rho \cdot L_y} \tag{3}$$

Therefore, the discharge voltage of the insulator will increase with an increase in the length of the leakage path and a decrease in the diameter of the insulator [6-7]:

$$U_{\text{вл.р}} = \frac{I_y \cdot \rho \cdot L_y}{\pi \cdot \Delta \cdot \text{B}} \tag{4}$$

Since the processes of drying the surface of the insulator occur relatively slowly, during short-term overvoltages, they do not have time to develop , and the breakdown voltage is higher than during long-term exposure to voltage.

The wet discharge voltage of the insulator depends on the characteristics the layer of pollution, its amount and composition, as well as the intensity and type of wetting. The wide variety of types of pollution encountered in operating conditions does not allow choosing a single "standard" pollution that could be applied to the surface of insulators when determining the wet discharge voltage. The most correct discharge voltage in real conditions of pollution and moisture can be determined from operational experience [8-11].

However, in theoretical calculations, in order to optimize the design of the concept, you can turn to the following method. The wet discharge voltage depends on the length of the path of the leakage current along the surface of the insulator between the electrodes (L_{ut}), as well as on the configuration of the insulator, the characteristics of the rain, and the type of voltage.

The wet discharge voltage of insulators is determined by alternating and pulse voltages. During the test, the insulator must be in a normal working position, rain jets must fall at an angle of 45° to the horizon with an intensity of 3 mm/min, water conductivity must be equal to 10-4 cm/cm. Voltage should be applied to the insulator 5 minutes after the start of moistening.

With a small protrusion of the ribs (*a/1<0.5*), the wet discharge voltage increases due to the increase in the length of the dry areas under the ribs. In this case, the discharge practically goes along the surface of the ribs .

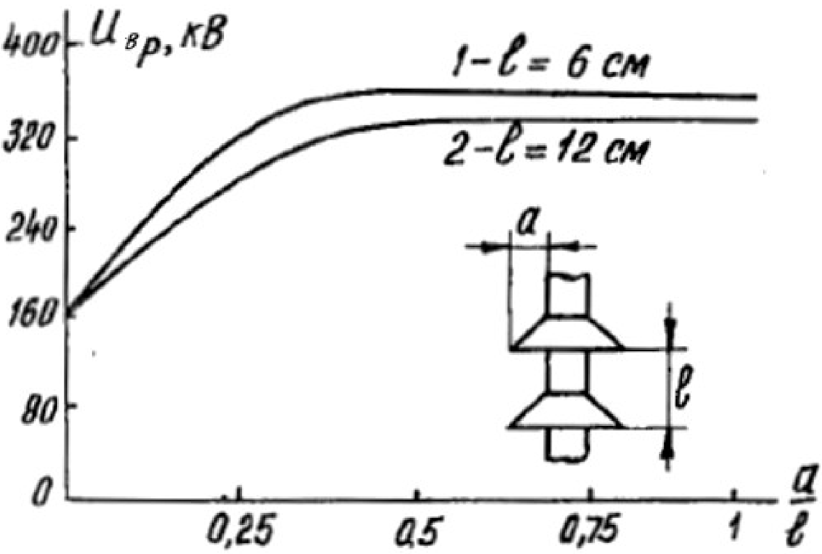

Fig. 1. Dependence *of* U_{vr} insulator from *a/l.*

An increase *in l* (at *a= const*) leads to a decrease. *Uvr* due to the reduction of dry zones under the ribs, so it should be reduced.

Experience shows that under normal conditions *the a/l ratio* should not exceed 0.5. *the a/l ratio* to 0.8-1.0 during the operation of the isolator under conditions of contamination .

The angle of inclination of the ribs is taken to be about 15-25 °.

When *a>30 mm,* the influence of the angle of inclination on U_{vr} is small. The rib must have a dripper so that water does not wet the lower surface of the rib and does not shrink the dry areas of the insulator surface. At an industrial frequency voltage and a rain rate of 5 mm/min, the minimum value of the wet discharge voltage can be determined by the formula (l_{chr} – in cm)

$$U_{вр} = 2{,}15 l_{схр}, \text{кВ}$$

Wet-discharge voltages at constant and alternating voltage are practically the same. Atmospheric conditions (pressure and temperature) have little effect on $U_{вр}$.

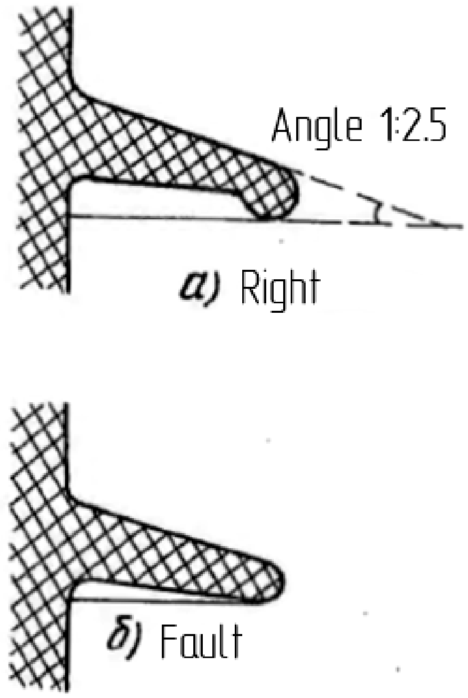

Fig. 2. Rib profile.

Despite the fact that rain does not affect underground power lines, however, general humidity and condensation are present. And here the rule already works that the higher the conductivity of water, which is as an aerosol in the air and on surfaces, the less $U_{in\,p}$.

Rain and moisture practically do not affect the impulse discharge voltage along the surface of the dielectric. The average moisture discharge voltage at f = 50 Hz is 2.1-2.4 sq /cm.

The main calculation parameter when choosing insulation for polluted areas is the specific length of the leakage path (l_{vit}), which is equal to the ratio of the total length of the leakage path L_{ut} to the largest operating linear voltage $U_{rob.l}$ ..

Depending on the insulator configuration, the discharge may partially travel through the air, which indicates the incomplete use of the length of the leakage path. For this purpose, the concept of the specific effective length of the leakage path is introduced [12]:

$$\lambda_{\text{пит}} = \frac{l_{\text{пит}}}{k} = \frac{L_{\text{вит}}}{U_{\text{роб.л}} \cdot k}, \text{см/кВ}$$

where k is a coefficient that takes into account the efficiency of using the length of the insulator leakage path.

For insulators with Lut /D ≤1.4 (D is the diameter of the insulator) k = 1.0-1.3 or can be calculated by the formula [13].

$$k = 1 + 0{,}5 \cdot \left[\left(\frac{L_{\text{вит}}}{D}\right) - 1\right]$$

Depending on the characteristics of the area and the danger of pollution sources, seven levels of atmospheric pollution are established, for each of which $\lambda_{\text{pit.ef}}$ is recommended when choosing insulation of 6-750 kV on metal and reinforced concrete supports.

For external insulation of electrical equipment, there are three categories of insulators according to the length of the leakage path: A – normal execution for isolators operating in conditions of low pollution; Б, В - reinforced and especially reinforced version for isolators working in conditions of severe and particularly severe pollution.

The length of the leakage path in insulators of category Б is 1.5 times, and in insulators of category B is 2.0 times greater than that of insulators of type A.

Therefore, when choosing the strength of the insulator, it is necessary to start from category B. However, this statement must be confirmed by calculating the effective specific leakage length.

Conclusions. The work analyzed the methods of calculating the effective length of the specific leakage path for insulators, it was established that the need to study project methods for underground substations and features of the influence of operating conditions in them (taking into account the influence of humidity and pollution). The process of forming the formation of the leakage current and the formulas for describing its parameters are presented. The dependencies and influence of the shape of the insulator on resistance to leakage currents are considered.

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