Increasing supporting rod porcelain isolate at electric power substations

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Abstract. Supporting rod insulation is intended for insulating and fastening cathode parts of electrical installations at electric power substations. The insulation is set at outdoor switchgear of substations as a part of the main switchgear equipment. During the operation, it is exposed to external atmospheric influences, mechanic and dynamic loads. Timely replacing supporting rod insulation significantly increases the reliability of the main substation equipment at electric power substations. There was considering a question about improving the reliability at transformer and traction substations, providing internal and external conditions affected the destruction of supporting rod porcelain insulation. It was determined that an important negative part of supporting rod porcelain insulation damage is sharp swings of ambient temperature, especially swinging values after 0 ºC. A model is suggested for applying a supporting rod porcelain insulator as an insulating body in the ellipse form. It was described the suggested device work. The temperature gradient was taken into account, which shows the intensity of the temperature changing, is a vector directed towards the increasing temperature. There is an equation of a temperature field, which describes a thermal state of the body and determines a degree of its heating. There is an analyzing interacting ratio of values of circle axis and oval from larger to smaller in the spatial positioning in power loads, comparing a section form. The calculation determined a post insulator in the ellipse form should be set in the way where the long axis will be compatible in the gradient direction of temperature for decreasing influences of heating to the minimal axis of the insulator.

1. Introduction

The largest part of substation equipment which undergoes wear is the supporting rod porcelain insulation (SRPI) (columns of isolators, discharges, high-voltages inputs, insulator garlands of Al and others). During the long operation of supporting pod porcelain insulators due to external factors (moisture, temperature swings, mechanic loads) and internal factors (violation of the technology to produce and quality of source materials) in volume of an insulating part of the porcelain insulator there can be generated cracks that lead to destruction of an insulator under a load [1-4].

There are many ways of diagnostic of SRPI such as the infrared thermography method, the controlling dielectric properties of insulation method, the vibration diagnostics method, the electrophysiological control method and others [5-9]. All methods are effective in certain conditions of diagnostics (decommissioning of equipment, applying special measure devices and others) and all defects cannot be covered adequately.

The relevance of the research of the problem is determined the government decree dated 27.10.2017 about "Scientific and technical development of The Russian Federation (RF) for 2018-2025 years" in which there is the transition to advanced digital, intelligent manufacturing technologies, robotic systems, new materials and approaches of constructing, creating system of processing large volume of data, machine learning and artificial intelligence [10].

The research goal is creating and using a model of reliability of a technical state of the supporting rod porcelain insulation at electric power substations for increasing reliability, failure risk assessment and warning of technological violations.

2. Analysing destruction (failures) of supporting rod insulators

Electrical ceramic materials products must comply with 20419-83 GOST. Ceramic and electrical materials. The classification and technical requirements [11].

Main reasons of insulator failure are the lack of node electrical durability: "a flange is the cathode part, the destruction of the protective coating, the breakdown (overlap) of actions of external lightning and internal overvoltages, and also the high temperature which is caused by the electric arc". Common defects include cracks, poor-quality reinforcement and impulsive breakdown of lightning currents.

Failures of insulators are distributed by insulator types: porcelain one is 25% from the total value, glass is 75%.

In figure 1 there are the most common types of porcelain insulator damages.

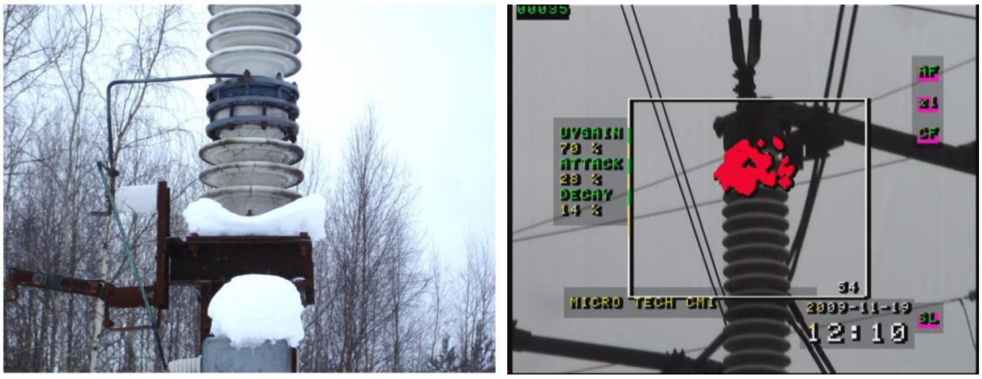

Figure 1. Damage of the thrust-rod porcelain insulators.

For increasing the reliability of the supporting rod porcelain insulation operation at transform and traction substations it is suggested the using supporting insulations in the ellipse form at the cross section, the long axis of which is compatible to the temperature gradient in conditions of spatial positioning. The arrangement of an insulating body influences to the supporting insulator service life.

3. The model of using the supporting rod porcelain insulator as an insulating body in the ellipse form

According the expression 1, where the circle shape is described, values are obtained [12]:

$$F = \frac{\pi \cdot d^2}{4} = \pi \cdot r^2 \approx 0{,}785 \cdot d^2, \qquad (1)$$

where F – sectional area, π –product perimeter, d – product diameter, r – figure radius.

Coordinated of extreme points of section are determined by formula 2:

$$x_1 = y_1 = \frac{d}{2} = r\,. \qquad (2)$$

In the circle, there is every central axis (x, y) is the main axis (figure 2).

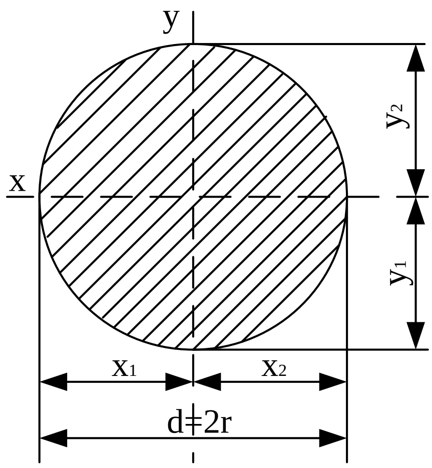

Figure 2. Shape of the circle section.

The ellipse form is determined by the expression 3, values are obtained by figure 3:

$$F = \pi \cdot a \cdot b\,, \qquad (3)$$

where a – coordinates of extreme axis pointsy, b – coordinates of extreme points of axis.

In the ellipse form, there are axis as x–x and y–y – main central (figure 3).

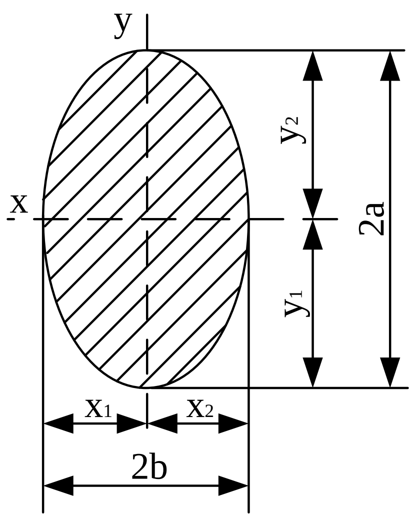

Figure 3. Shape of the ellipse section.

In figure 4, there is the frontal section of the supporting insulator in the ellipse form.

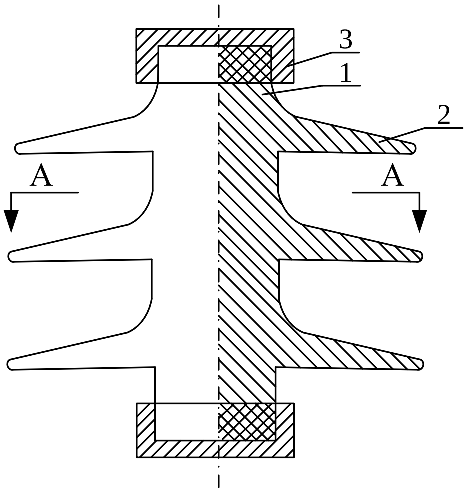

Figure 4. Frontal section of the supporting insulator elliptical shape: 1 - connecting walls of the insulating body of the support insulator of elliptical shape; 2 - ring ribs of elliptical shape of the insulating body of the support insulator; 3 - metal caps.

The supporting insulator installed as an isolator column isolates the conductive and non-conductive parts. At the isolator, a metal flange 3 is set at which insulating body of the supporting insulator in the ellipse form is connected through connective walls 1 with a concrete mortar and ellipsoidal annual ribs 2. The supporting insulator is set due to the ellipse long axis is compatible with the temperature gradient direction.

The appearing the temperature in the gradient body leads to the appearing the heat flux (the thermal conductivity) which is exist while the gradient is not equal to zero due to the energy transfer.

The complex of temperature values in all points of a body at the moment is a temperature field and it is determined by expression 4:

$$t = F(x, y, z), \tag{4}$$

where t –the body temperature in a point; x, y, z – point coordinates; t – the time.

At any temperature field in the body there are points with the same temperature. At the one hand, there cannot be two different temperatures, and therefore isothermal surfaces do not touch and intersect. At the other hand, ends at body frames, either makes up the closed loop (for example, in the cylindrical shape). The temperature change in the body is observed just in directions, which are crossed isothermal surfaces. In the case, the most rapid change of temperature is observed in directions, which are obvious to isothermal surfaces. The temperature changes ratio limit (*dt*) to minimal distance between these isotherms (*dn*) is the temperature gradient [13-15], which is determined by formula 5:

$$\lim_{\Delta n \to 0}\left(\frac{\Delta t}{\Delta n}\right) = gradt = \frac{dt}{dn}, \tag{5}$$

The temperature gradient reveals the intensity of temperature changes and it is a vector directed to increasing temperature.

As temperature gradient, there is taking the solar heat directed to the insulator.

In figure 5, there is the horizon view of the A-A section of figure 4.

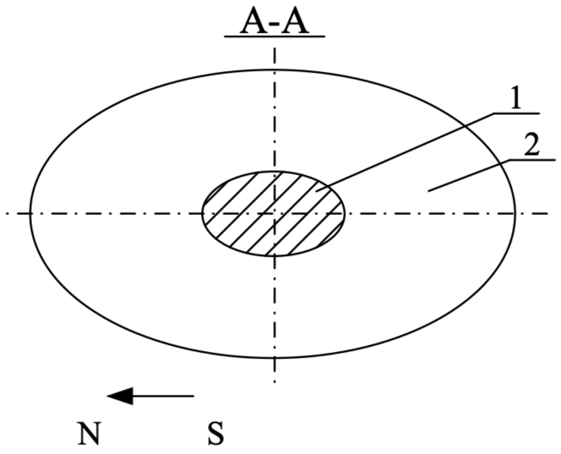

Figure 5. Horizontal view in the section A-A of the ellipsoidal support insulator:
1 - connecting walls of the insulating body of the support insulator of elliptical shape;
2 - ring ribs of elliptical shape of the insulating body of the support insulator.

4. Results and discussions

The results of comparing mathematic models of SRPI in the ellipsoidal and the traditional forms show that for increasing the reliability of the SRPI operation at transform and traction substations the using ellipsoidal supporting insulators increases the service life of the supporting insulator. The uniqueness of the approach is confirmed by obtaining a patent for the utility model [16].

According main indicators of choosing a figure shape in the table it shown interactions of the ratio between values of the circle axis from greater to smaller in the spatial positioning in power loads.

Table 1. The relationship between the ratio of the axis of the circle and the oval from greater to smaller in the spatial positioning in power loads.

Indicator	Circle, D = 16 mm	Ellipse	
Axle length, mm	16×16	20×12.8	32×8
The ratio of the values of the axes	i=1.0	i=1.5625	i=4
Cross-sectional area, cm^2	2.0096	2.0096	2.0096
Moment of resistance on maximum axis, cm^3	0.40192	0.5024	0.80384
Moment of resistance on minimum axis, cm^3	0.40192	0.3215	0.20096
Total moment of resistance, cm^3	0.80384	0.8239	1.0048

According the table, moments of resistance in axis of maximal load of the oval with different ratio between the largest axis to the smallest axis and the square, which is equal to the square of the cross-sectional area in 16 mm, increase. Resistance moments in the axis of minimal load in the same conditions slightly decrease.

5. Conclusion

It has been established that the supporting rod porcelain insulation at transform and traction substations is the most available to damage due to affections of external and internal factors.

For increasing the reliability of the supporting rod porcelain insulation operation at transform and traction substations it is suggested supporting insulators in the ellipsoidal form at the cross section, the long axis of which is compatible with the temperature gradient in the spatial positioning conditions.

The using the insulating porcelain body in the ellipsoidal form increases the total moment of the supporting insulator resistance to 0.8239 compared the circle values in 0.80384 см^3, that provides the increasing the insulator reliability.

The supporting insulator in the ellipsoidal form is installed when the long axis is compatible with the temperature gradient direction, it is the sunlight for decreasing the influence of the heating at the insulator minimal axis.

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