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Mechanism of sudden flashover on composite insulator surface with non-uniformly distributed wettability and pollution

Abstract. *This paper presents the mechanism of a sudden flashover along composite insulator surface with non-uniformly distributed wettability and pollution. Parameters of the model have been determined on the basis of typical composite insulator pollution characteristics in a condition of low or high surface wettability. It has been found that surface strength of composite insulator with non-uniformly distributed wettability and pollution depends mainly on a part of its creepage distance (of low wettability) – around 25% of insulator's overall creepage distance.*

Streszczenie. *W artykule przedstawiono mechanizm natychmiastowego przeskoku napięciowego po powierzchni izolatora kompozytowego o nierównomiernej zwilżalności i nierównomiernym zabrudzeniu. Parametry modelu określono na podstawie typowych charakterystyk zabrudzeniowych izolatora kompozytowego w stanie niskiej lub wysokiej zwilżalności. Stwierdzono, że wytrzymałość powierzchniowa izolatora kompozytowego zależy głównie od części jego drogi upływu (około 25% całkowitej długości) wzdłuż powierzchni o niskiej zwilżalności.(**Mechanizm natychmiastowego przeskoku napięciowego na powierzchni izolatora kompozytowego o nierównomiernej zwilżalności i zabrudzeniu)***

Keywords: pollution flashover, pollution characteristic, surface wettability, composite insulator, creepage distance
Słowa kluczowe: przeskok zabrudzeniowy, charakterystyka zabrudzeniowa, zwilżalność powierzchni, izolator kompozytowy, droga upływu

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Introduction

The problem of pollution flashover along the surface of a long rod composite insulator is interesting both in a cognitive sense (mechanism of a flashover) and in a practical aspect, in relation to dimensioning composite insulators under operating conditions.

In accordance to the experimental research results [1, 2] the flashover along the low-wettability surface of an insulator may take place due to the creation of hydrophilic runnel of joined together water drops in the presence of a strong electric field.

It is important to emphasize that flashovers on hydrophobic composite insulators are usually registered at voltage levels significantly higher than operating voltages of electric power grids in which those insulators are installed. Consequently such composite insulator, particularly in HTM (hydrophobicity transfer material) housing, dimensioned as a traditional insulator (porcelain or glass) is actually not exposed to pollution flashovers, provided that operating conditions have been suitably determined [3]. In such conditions pollution flashover research has purely cognitive aspect and is not a subject of this study.

Under operating conditions, during long period of environmental factors impact, some elements of composite insulator surface may partially lose low wettability. It can affect mainly surfaces adjacent to a hot end of the insulator, shed edges, and first shed surface from the side of a grounded fitting [4, 5, 6].

Eventually, on the surface of the composite insulator there may appear a non-uniform distribution of areas characterised by diversified state of wettability and hence diversified pollution [4, 6, 7, 8, 26].

It has been assumed in this paper that a hydrophilic surface of composite insulator does not substantially differ from the surface of a traditional insulator and under operating conditions may be affected by pollution to varying degrees [27].

The assumption concerning diversity of composite insulator surface wettability consequently means the consideration of insulator covered with non-uniform pollution layer [9].

This case has rarely been analysed in pollution flashover theory because of difficulty with description of such pollution layer [10-15]. Most studies covered the analysis of flashover on uniformly polluted traditional insulators [16].

In this paper, it has been attempted to use a classic Obenaus – Neumärker theory [17, 18, 19] for the description concerning the mechanism of flashover on a long rod composite insulator.

The objective of performed analyses and calculations was to determine pollution flashover voltage of a composite insulator of which only a part of creepage distance maintained a low wettability [9].

It is particularly interesting to compare composite insulator's strength in low-wettability condition on the whole surface with the strength of this insulator when a major part of its surface became hydrophilic and may be highly polluted.

It has been assumed that the distribution pattern of low- or high-wettability (and pollution) areas is not significantly affecting the insulator's flashover voltage [16, 17, 20]. The meaning of a total length of low- or high-wettability creepage distance sections (X_1 and X_2) is important [9].

The constants in Obenaus equations were introduced on the basis of composite insulator pollution characteristics presented in selected publications [9, 21, 22, 23].

The development of composite insulator sudden flashover analysis carried out in this paper generally refers to a direct voltage. However it is not crucial to analyse differences in flashover development under the operation of insulators in DC or AC electric power networks, but the physical mechanism that explains the occurrence of a sudden flashover.

Pollution characteristics of long rod insulators. Tangential component of the electric field along a cylindrical insulator

Figure 1 presents the composite and porcelain insulator pollution characteristics.

The characteristic (1) refers to composite insulator pollution flashover voltage with hydrophobic surface and HTM (hydrophobicity transfer material) housing [3].

On such surface water drops persist mainly on shed surface and measured contact angles are ranging from 90° to 100°. Angles of slope s according to equation (1), of composite insulator pollution characteristics are usually in the range of 0,01-0,15 while the constant n of static-arc characteristic adopt similar values [7, 9, 21-23].

Surface flashover voltage under these condition can be hardly described as pollution flashover because of practical lack of its dependence on applied pollution level (Figure 1).

Minor slopes of long-rod composite insulator pollution characteristics are mainly the result of housing material low wettability and geometrical shape of those insulators which is much more favourable when considering self-cleaning abilities than shapes of porcelain or glass insulators. (Fig. 1, characteristic 3) [5, 20]

(1) $$s = \frac{n}{1+n}$$

Slopes of characteristics of hydrophilic composite insulators are usually smaller than for traditional insulators, due to previously mentioned composite insulators' better geometry in the context of pollution flashover development. Usually these slopes are around 0,2-0,3 [21-23].

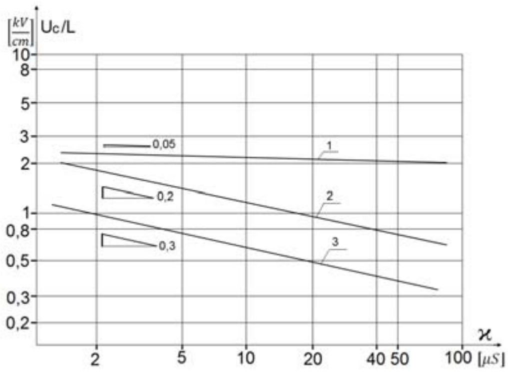

Fig. 1. Double-logarithmic scale pollution characteristics of long rod composite insulator (1, 2) and long rod porcelain insulator (3). 1. Characteristic for composite insulator with hydrophobic surface, 2. Characteristic for composite insulator with hydrophilic surface

It should be mentioned that characteristics in Figure 1 are the so-called uniform layer pollution characteristics that practically refers only to laboratory tests. In the analysis carried out in this study, those characteristics are considered as reference to results of performed calculations.

As stated before, the composite insulator, particularly in HTM housing, after numerous years of operation has areas of diversified wettability on a housing surface. High conductivity electrolytic film that covers hydrophilic areas may initiate flashovers as a result of leakage current flow. Low wettability areas can strongly limit leakage current development. Thus the pollution flashover (or the lack of it) is determined by a proportion of low-to-high wettability insulator creepage distance sections and a value of pollution measured as SDD (ESDD) or surface conductivity κ [9, 20].

In the view of leakage current limitation (up to mA singular values), by composite insulator low wettability surface areas, the phase of intense arc development (partial arcs development) does not occur. However, sudden flashovers are observed immediately after low wettability insulator section is bridged with arc. Such a process is connected with highly non uniform electric field distribution along non-uniformly polluted composite insulator, which enables the arc ignition over a low wettability creepage distance section.

Figure 2 presents the electric field distribution along non-uniformly polluted porcelain cylindrical insulator, calculated using an integral equation method [24].

It can be noticed (Fig. 2) that the electric field tangential component E_t value along a slightly polluted creepage distance section of non-uniformly polluted cylindrical insulator is practically the same (no drop of E_t value) and that allows for electric arc ignition at some level of E_t value. On the other hand a voltage drop along the slightly polluted creepage distance section is much bigger than along the remaining part of the insulator [24].

The scale of pollution distribution diversity on both insulator's sections has not significantly affected the shape of the tangential component of the electric field distribution.

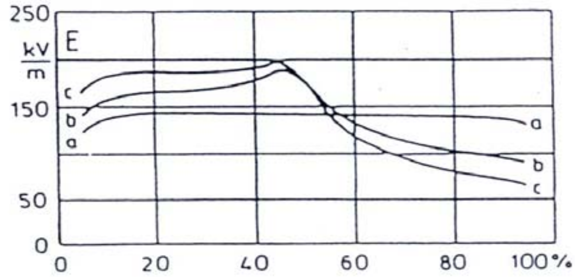

Fig. 2. Calculated distributions of the tangential component E_t of the electric field along the cylindrical insulator polluted with non-uniform layer. a) uniform layer on the entire surface of the insulator, b) non-uniform layer, conductivity relationship for layers on both halves of the insulator surface equals 1:2, c) Non-uniform layer, conductivity relationship for layers on both halves of the insulator surface equals 1:4

One may thus assume that because a limited voltage drop along an electric arc channel the arc root transits the potential of electrode located next to the lower polluted section of a creepage distance to the edge of a higher polluted section. If this potential is sufficiently high, then after reaching the edge of a higher polluted section of a creepage distance, the arc extension occurs, on the expense of electric energy source power as well as pollution flashover on the insulator. This flashover immediately takes place and is not connected with partial arcs occurrence and their development.

The sudden flashover may also take place on conventional insulators covered with a non-uniform pollution layer if conditions of such a layer's proper modelling are fulfilled [11].

Mathematical models of flashover phenomenon under condition of modelling the non-uniform pollution layer on long rod porcelain insulators are presented in [10,11,15,20].

Electric model and its fundamental mathematical equations

A starting point for the discussion is an analysis of an arc burning on the surface of an insulator, the remaining part of which is not bridged with arc (Fig. 3a). If the voltage of a burning arc U_N is written with the equation (2):

(2) $$U_N = NXI^{-n}$$

where: n and N are constants of the static-arc characteristic and X is the arc length then the equation (3) of voltage drop along the insulator surface, ΔU is a voltage drop near electrodes can be expressed as:

(3) $$U = U_S - \Delta U = NXI^{-n} + I\,R_p$$

where: U is a voltage along an insulator, Us is the voltage applied to insulator fittings, I is the arc current and Rp is the resistance of an insulator section, which is not bridged with a burning arc.

If insulator surface is polluted with a uniform layer, the resistance Rp can be determined as (4):

(4) $$R_p = r_p\ (L-X)$$

where: r_p – resistance per unit length of the insulator covered with polluted layer and L is the length of a creepage distance of an insulator.

Further, differentiating equation (3), in accordance with equations (5) and (6) and inserting (4):

(5) $$\frac{dU}{dX} = 0$$ and

(6) $$\frac{dU}{dI} = 0$$

it can be shown that current I, necessary to sustain the arc of length X can be given by the equation (7)

(7) $$I = \left[\frac{nNX}{r_p(L-X)}\right]^{\frac{1}{1+n}}$$

and critical values of arc length X_c current I_c and voltage U_c can be calculated as:

(8) $$X_c = \frac{L}{1+n}$$

(9) $$I_c = \left(\frac{N}{r_p}\right)^{\frac{1}{1+n}}$$

(10) $$U_C = N^{\frac{1}{1+n}} r_p^{\frac{1}{1+n}} L$$

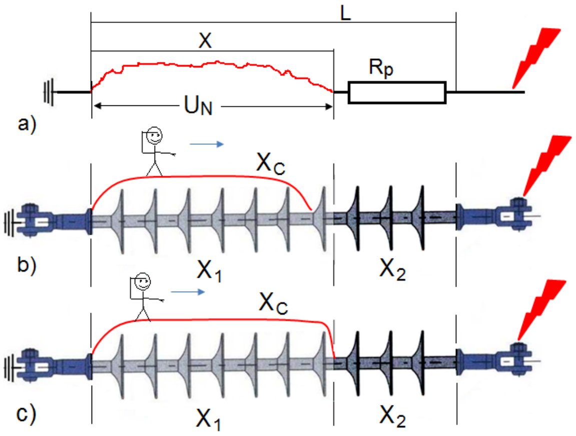

Figure 3. Electric model of a polluted insulator and a composite insulator of diversified wettability of surfaces of creepage distance sections (X_1 and X_2) and of surface conductivities κ_{p1} and κ_{p2} respectively:

a) arc X on insulator part with remaining part of resistance R_p (not bridged with arc),

b) $X_1 > X_C$, $\kappa_{p1} < \kappa_{p2}$,

c) $X_1 \approx X_C$, $\kappa_{p1} < \kappa_{p2}$

Critical arc length on a composite insulator

Critical arc length X_C not longer than partially hydrophobic and polluted section length X_1.

In order to simplify the analysis, it is assumed that the insulator, as presented in Fig. 3b, is totally hydrophilic only near a hot end of an insulator and arc X_c is shorter than section X_1.

If section X_1 is hydrophobic then a pollution partial arc cannot develop along this surface and surface flashover can be subjected to rules of streamer discharge initiated flashover development. The probability of existence of flashover at a level of operating voltage of transmission or distribution system under these conditions is very low. If section X_1 of a composite insulator is partially hydrophilic and polluted (Figure 3b and 3c) as a result of operational treats [6] then the pollution layer along the insulator is strongly non uniform and surface flashover can be compared to those on traditional insulators

In Fig. 3b, the observer, placed near a grounded end of the insulator, wonders what influence the composite insulator totally hydrophilic section of the creepage distance X_2 has on the critical length of the X_C arc.

If :

(11) $$L = X_1 + X_2$$

then the resistance R_p (4) of not bridged with an arc part of non-uniformly polluted insulator can be written as :

(12) $$R_p = r_{p1}\ (X_1 - X) + r_{p2}\ (X_2)$$

While the critical arc length X_C can be calculated by applying equations (7) and (9) (Fig. 3b):

(13) $$\lim_{X \to X_C} \left[\frac{n_1 N_1 X}{r_{p1}(X_1 - X) + r_{p2} X_2}\right]^{\frac{1}{1+n_1}} = \left[\frac{N_1}{r_{p1}}\right]^{\frac{1}{1+n_1}}$$ or

(14) $$X_C = \frac{X_1 + \beta X_2}{1+n_1}$$ where:

(15) $$\beta = \frac{r_{p2}}{r_{p1}} = \frac{\kappa_{p1}}{\kappa_{p2}} << 1$$

κ_{p1} and κ_{p2} are surface conductivities of sections X_1 and X_2 of the composite insulator.

The equation (14) was previously given in works [10, 11] as a result of analyses of voltage distribution along a non-uniformly polluted long rod porcelain insulator. As long as the critical arc length X_C is smaller than the length of section X_1, a small section X_2 hardly influence the X_C length. That can be interpreted, by an observer placed near a grounded end of the insulator (Fig. 3b), as a relative shortage of the X_2 section, and the same way insulator creepage distance L.

In the case shown in Fig. 3c the arc root of a critical arc X_C is close to limit of section X_2 of resistance per unit length r_{p2} . It can be assumed that at the same time occurs the increase of arc current resulting from a smaller pollution resistance per unit length r_{p2} *of* X_2 section [10, 11].

Then:

(16) $$\lim_{X \to X_C} \left[\frac{n_1 N_1 X}{r_{p1}(X_1 - X) + r_{p2} X_2}\right]^{\frac{1}{1+n_1}} \le \left(\frac{N_2}{r_{p2}}\right)^{\frac{1}{1+n_2}}$$

hence:

(17) $X_C \le \dfrac{X_1 + \beta X_2}{1 + C_n}$ where:

(18) $C_n = n_1 \alpha\, \beta\, \kappa_{p2}^{\ 1-k} << 1$

(19) $k = \dfrac{1+n_1}{1+n_2}$ and

(20) $\alpha = \dfrac{N_1}{N_2^{\ k}} \sim 1$

Eventually it can be assumed that regardless the arc critical length X_C, provided that it fits entirely within the length of a creepage distance, section X_2 practically does not influence the critical arc length X_C (14 and 17).

Critical arc length X_C longer than section X_1

Let's assume that as a result of long-term operating exposure threats a large part of the composite insulator surface became wettable (section of a creepage distance X_2) as a result of which a critical arc length X_C is greater than the section of creepage distance X_1. Such case is presented in Fig. 4.

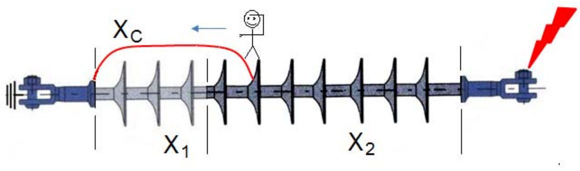

Fig. 4. Composite insulator of diversified wettability of sections of a creepage distance X_1 and X_2, which correspond to surface conductivities κ_{p1} and κ_{p2} or resistances per unit length r_{p1} and r_{p2} . It has been assumed that $X_C > X_1$.

The observer placed near arc root of a critical arc length X_C (Fig. 4) wonders which way X_1 section can contribute to development of X_C arc.

In order to determine this contribution let's consider two model cylindrical insulators as presented in Fig. 5. There is a partial arc on each of those insulators. We assume that constants n and N for arcs and insulators are comparable. Surfaces of insulators have different surface resistances r_{p1} and r_{p2} with partial arcs of lengths X_1 and X. In both cases the insulators sections which are not bridged with arc are of X_2 length.

For the case presented in Figure 5, the equation of arcs currents (7) can be written as:

(21) $\left(\dfrac{nNX_1}{r_{p1}X_2}\right)^{\frac{1}{1+n}} = \left(\dfrac{nNX}{r_{p2}X_2}\right)^{\frac{1}{1+n}}$ and further:

(22) $X = \beta X_1$ where:

X is the length of an arc burning on the surface of the model cylindrical insulator of pollution resistance per unit length r_{p2} .

X_1 is the length of an arc burning on the surface of the model insulator of pollution resistance per unit length r_{p1} .

X_2 is a not bridged with arc section of the creepage distance of an insulator.

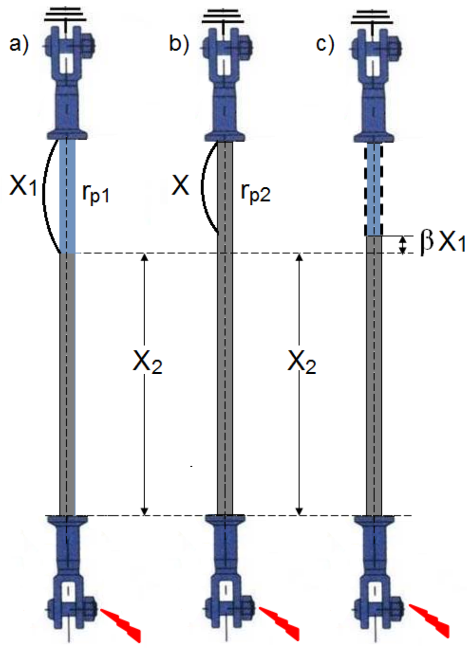

Fig. 5. The model cylindrical insulators of diversified values of surface pollution resistances per unit length r_{p1} and r_{p2} .a) insulator with a partial arc of X_1 length b) insulator with a partial arc of X length c) equivalent insulator of a uniform pollution resistance per unit length r_{p2} .

It follows that (22) for the observer in Fig. 4 the section X_1, bridged with arc, has been shortened β -times and that is why the insulator can be presented as in Fig.5c, as uniformly polluted of which the shortened creepage distance L_2 can be written as:

(23) $L_2 = X_2 + \beta X_1$

Thus a following equation (24) can be written further:

(24) $\lim\limits_{X \to X_C} \left[\dfrac{n_2 N_2 X}{r_{p2}\left(X_2 + \beta X_1 - X\right)}\right]^{\frac{1}{1+n_2}} = \left(\dfrac{N_2}{r_{p2}}\right)^{\frac{1}{1+n_2}}$

hence

(25) $X_C = \dfrac{X_2 + \beta X_1}{1+n_2}$

The relationship (25) indicates that X_1 creepage distance section, bridged with arc, practically does not influence a critical arc length X_C .

Critical voltage U_{CN} of composite insulator with non-uniformly distributed surface wettability and pollution

Critical voltage U_C of uniformly polluted composite insulator is described with an equation (10). As presented in Fig. 2 electric field applied to a cylindrical porcelain insulator covered with a layer of non-uniform pollution, has a non-uniform distribution [24].

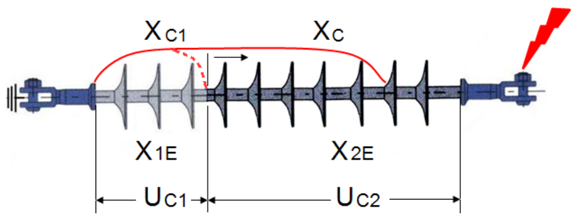

Fig. 6 Ignition (in section X_{1E}) and propagation of electric arc (in section X_{2E}) correspond to the occurrence of a sudden flashover on a long rod composite insulator surface with non-uniformly distributed wettability. Critical voltages U_{C1} and U_{C2} have similar values and X_{C1}, X_C are arcs that burn on X_{C1} section and on the whole insulator respectively.

On a slightly polluted section of insulator's creepage distance the value drop of tangential component of an electric field practically does not exist. However it can be observed mainly along a heavily polluted part of the insulator. Therefore it can be assumed that at a certain level of insulator's pollution, described by the division of creepage distance in sections X_{1E} and X_{2E}, of surface conductivities κ_{p1} and κ_{p2} respectively, such a voltage distribution on the insulator occurs that arc ignition along its part X_{1E} will cause its immediate extension, for X_{2E} part until the critical length of X_C and consequently a sudden flashover on insulator.

Such a voltage division on composite insulator surface with non-uniformly distributed wettability (and pollution) is assumed to be called here as the critical voltage of a sudden flashover U_{CN}.

This as if corresponds to a composite insulator's division into two component insulators where critical voltages U_{C1} and U_{C2} for these both insulators are calculated assuming their similar values.

Assumptions adopted here (Fig. 6) result from properties of fallen electric arc characteristic [25]. Arc propagation in section X_2 does not require a voltage increase but only an adequate power of electric energy source.

Taking into consideration equations (8), (10), (14), (17) and (25) we can obtain:

$$\frac{L_1}{1+n_1} = \frac{X_1+\beta X_2}{1+C_n} \tag{26}$$

$$\frac{L_2}{1+n_2} = \frac{X_2+\beta X_1}{1+n_2} \tag{27}$$

where L_1 and L_2 are relatively shortened creepage distances of composite insulator, also

(28) $U_{CN} = U_{C1} = U_{C2}$ and

$$N_I^{\frac{1}{1+n_1}} r_{p1}^{S_1} \frac{1+n_1}{1+C_n}\left(X_{1E}+\beta X_{2E}\right) = N_2^{\frac{1}{1+n_2}} r_{p2}^{S_2}\left(X_{2E}+\beta X_{1E}\right) \tag{29}$$

Equations (28) and (29) can be written because the critical voltage U_{C1} for slightly polluted (or hydrophobic) section X_1 of a composite insulator can be described with equation (10) on the basis of constants obtained from characteristic 1 in Figure 1 (despite a streamer initiated flashover along this section). Since parameters n_1 and C_n take numerical values much smaller than unity and taking into account the equation (20) we can get :

$$X_{1E}+\beta X_{2E} = \alpha^{-1}\kappa_{p2}^{-S_2}\kappa_{p1}^{S_1}\left(X_{2E}+\beta X_{1E}\right) \tag{30}$$

and also

$$X_{1E} = X_{2E}\,\frac{\alpha^{-1}\kappa_{p2}^{-S_2}\kappa_{p1}^{S_1}-\beta}{1-\alpha^{-1}\kappa_{p2}^{-S_2}\kappa_{p1}^{S_1}\beta} \tag{31}$$

Taking into account (11), the equation (31) can be further transformed to:

$$X_{1E} = \frac{\alpha^{-1}\kappa_{p2}^{-S_2}\kappa_{p1}^{S_1}-\beta}{(1-\beta)\left(1+\alpha^{-1}\kappa_{p2}^{-S_2}\kappa_{p1}^{S_1}\right)}\cdot L \tag{32}$$

$$X_{2E} = \frac{1-\alpha^{-1}\kappa_{p2}^{-S_2}\kappa_{p1}^{S_1}\beta}{(1-\beta)\left(1+\alpha^{-1}\kappa_{p}^{-S_2}\kappa_{p1}^{S_1}\right)}\cdot L \tag{33}$$

The division of long-rod creepage distance composite insulator into sections X_{1E} and X_{2E} corresponding to hydrophobic and hydrophilic parts will result in an immediate flashover in pollution tests.

On the basis of equations (32) and (33) equivalent conductivity κ_E can be calculated considering equations (34) or (35). That brings the problem of non-uniform pollution (as a consequence of non-uniform wettability) to the case of uniformly polluted composite insulator.

Such equivalent conductivity κ_E can be defined as:

$$\kappa_E = \frac{X_{1E}}{L}\kappa_{p1} + \frac{X_{2E}}{L}\kappa_{p2} \tag{34}$$

and after transformations:

$$\kappa_E = \frac{\left(\alpha^{-1}\kappa_{p2}^{-S_1}\kappa_{p1}^{S_1}-\beta\right)\kappa_{p1}+\left(1-\alpha^{-1}\kappa_{p2}^{-S_2}\kappa_{p1}^{S_1}\beta\right)\kappa_{p2}}{(1-\beta)\left(1+\alpha^{-1}\kappa_{p2}^{-S_2}\kappa_{p1}^{S_1}\right)} \tag{35}$$

Maximum lowering of composite insulator flashover voltage caused by non-uniform wettability of its surface

Flashover voltage lowering of composite insulator with non-uniform surface wettability shall be, first of all, related to electric strength U_C of this particular insulator in the hydrophobic state of its whole surface (36).

$$\frac{U_{CN}}{U_C} = \frac{N_1^{\frac{1}{1+n_1}}\kappa_{p1}^{-S_1}\left(X_{1E}+\beta X_{2E}\right)}{N_1^{\frac{1}{1+n_1}}\kappa_{p1}^{-S_1}L} = \frac{X_{1E}+\beta X_{2E}}{L} \tag{36}$$

Applying equivalent conductivity κ_E in the equation (36) enables to calculate the maximum lowering of electric strength U_{CN} of composite insulator with diversified surface wettability at different levels of pollution (Table 1, Figure 7). This flashover voltage lowering is calculated in relation of the composite insulator surface strength U_{CN} to the strength of this insulator in conditions of low wettability of its whole surface. One may also calculate this strength lowering (Table 1, Figure 7) in relation to electric strength of composite insulator with hydrophilic surface (37).

$$(37) \qquad \frac{U_C N_2}{U_{C2}} = \frac{N_2^{\frac{1}{1+n_2}} \kappa_{p2}^{-s_2}\left(X_2 + \beta X_1\right)}{N_2^{\frac{1}{1+n_2}} \kappa_{p2}^{-s_2} L} = \frac{X_{2E} + \beta X_{1E}}{L}$$

Table 1. Maximum lowering of flashover voltage U_{CN} / U_C and U_{CN_2} / U_{C_2} of the non-uniformly polluted composite insulator.

κ_{p1} $[\mu S]$	κ_{p2} $[\mu S]$	κ_E $[\mu S]$	β	$\frac{U_{CN}}{U_C}$	$\frac{U_{CN_2}}{U_{C_2}}$	$\frac{X_{1E}}{L}$	$\frac{X_{2E}}{L}$	$\frac{X_C}{L}$
$s_1 = 0{,}05$, $s_2 = 0{,}2$								
2	50	39,7	0,40	0,24	0,80	0,21	0,79	0,64
2	40	32,0	0,05	0,26	0,80	0,22	0,78	0,64
2	30	24,0	0,07	0,28	0,80	0,22	0,78	0,64
2	20	15,9	0,10	0,30	0,80	0,22	0,78	0,64
$s_1 = 0{,}1$, $s_2 = 0{,}2$								
2	50	39,9	0,04	0,24	0,80	0,21	0,79	0,64
2	40	32,0	0,05	0,27	0,80	0,21	0,79	0,64
2	30	23,8	0,07	0,28	0,80	0,22	0,78	0,64
2	20	16,0	0,10	0,30	0,80	0,22	0,78	0,64
$s_1 = 0{,}15$, $s_2 = 0{,}2$								
2	50	39,0	0,04	0,26	0,78	0,23	0,77	0,63
2	40	31,3	0,05	0,27	0,78	0,23	0,77	0,63
2	30	23,6	0,07	0,28	0,79	0,23	0,77	0,63
2	20	15,7	0,10	0,32	0,79	0,24	0,76	0,63

Table 1 presents the calculation results with agreement to proposed composite insulator sudden flashover mechanism model assuming slope of characteristics 1, in Fig. 7, in the range of 0,05-0,15 that is typical range known from the references [21-23]. It can be noticed that low wettability creepage distance section X_{1E}, which length is about 25% of overall insulator creepage distance length L, decides about surface electric strength of the whole insulator. Pollution level of the remaining part of the insulator has little effect on flashover voltage. In similarity a slope change of the characteristic 1, in the range of 0,01-0,15, does not practically affect the length of X_{1E} section (32).

The critical length X_C of the arc (calculated in accordance to (25)) is comparable to the length of X_{2E} section. It can suggests an arc sudden development from its initial length X_{1E} , to a critical length X_C , already on X_{2E} section.

The flashover voltage lowering of composite insulator with non-uniformly wettable surface may be around, according to calculation results in Table 1, 70% of the flashover voltage of this particular insulator, when its whole surface is characterised by low wettability.

However, the insulator's flashover voltage lowering, in relation to the electric strength of the polluted composite insulator, in the hydrophilic state may be around 15-20%.

Fig. 7 presents pollution characteristics (3, 4, 5) of composite insulator with non-uniformly distributed wettability calculated on the basis of (35) and (37) equations and data from Table 1 (S_1 = 0,05, S_2=0,2). It can be noticed that curve 6 in Fig.7 is a geometric place for points of maximum lowering of surface strength of composite insulator, at different level of its pollution and wettability described with characteristics 3, 4 and 5. If composite insulator pollution strength is 20-30% higher than pollution strength of comparable traditional insulator, even in hydrophilic state of its surface [9, 22, 23] then consequently, a composite insulator will always have pollution strength not lower than a traditional insulator

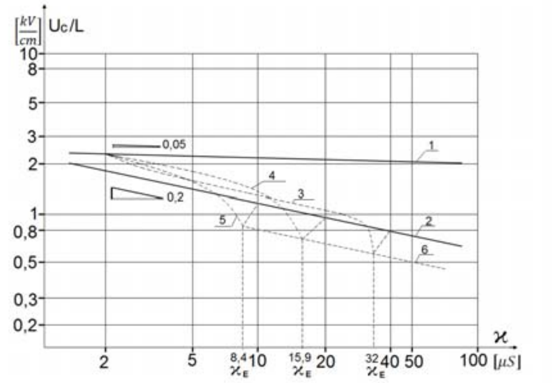

Figure 7. Pollution characteristics of a composite insulator.

1- pollution characteristic of insulator with hydrophobic surface.

2- Pollution characteristic of insulator with hydrophilic surface.

3,4,5- Pollution characteristics of composite insulator with non-uniformly distributed wettability of creepage distance sections X_{1E} (hydrophobic) and X_{2E} (hydrophilic) covered with pollution layers of surface conductivities 2 and 40μS (3), 2 and 20μS (4) and 2 and 10μS (5) respectively, like in Table 1.

6- geometric place of composite insulator pollution surface strength's minimal values.

It can be noticed also that shape of pollution characteristics, similar to those in Fig. 7, have been obtained as a result of experimental measurements and computational methods for long rod ceramic insulators covered with two pollution layers of different surface conductivity and thickness (NSDD) [11, 15, 20].

Sudden flashovers were also observed there, what was determined by highly non-uniform distribution of a pollution layer. It seems that a sudden flashover on composite insulator with non-uniformly distributed wettability and pollution belongs to the same category.

Conclusions:

The analysis conducted in this paper concerning a sudden flashover occurrence on composite insulator, with a non-uniformly polluted surface resulting from non-uniform wettability and environmental influence, allows for to the following conclusions:

- A sudden flashover on a composite insulator is the result of highly non-uniform distribution of the electric field tangential component and voltage along the insulator, caused by non-uniform distribution of surface pollution that is relevant to insulator surface's non-uniform wettability caused by the environmental exposure in an operation place.
- A sudden flashover occurs when a creepage distance section X_1 (of low wettability) of a proper length X_{1E} is bridged with arc, what immediately causes extension of the arc on a creepage distance section X_2 (hydrophilic) and flashover on the whole insulator. It is possible because of falling characteristics of the arc and only limited voltage drop along the arc channel.
- Low wettability creepage distance section X_1 is critical for composite insulator's pollution flashover voltage when it is about 25% of overall insulator creepage distance.

- Arc critical length is comparable with the length of polluted and hydrophilic X_{2E} section. It suggests the arc extension, above X_{1E} section, on creepage distance section X_{2E} (hydrophilic and polluted) and the occurrence of a sudden flashover.
- Voltage lowering of composite insulator due to sudden flashover can be around 70% compare to flashover voltage of the insulator with hydrophobic surface.
- Pollution flashover voltage of composite insulator with non-uniform wettability of local areas on its surface and consequently non-uniformly polluted is not lower than a surface strength of uniformly polluted traditional insulator of comparable shape geometry and creepage distance length.
- The sudden flashover mechanism takes place also in case of non-uniformly polluted traditional insulators, particularly when surfaces of those insulators are covered with pollution layers of diversified surface conductivities and thickness (NSDD). Mechanisms of the flashover are similar in both cases.

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