INFLUENCE OF FLOATING OBJECTS ON THE DIELECTRIC STRENGTH OF AIR GAPS IN THE FRAME OF LIVE-WORKING

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Abstract: Compliance with the minimum approach distances during the live working is the theoretical base of the Live Working. The IEC 61472 standard specifies a method of calculation of the minimum approach distances specially adapted for the levels of the voltage range superior to 72,5 kV. The consideration of the influence of electrically floating objects on the dielectric strength is defined in IEC 61472 - Annex F. However, the following case is not taken into account, both in the studies CIGRE, and in the IEC 61472 standard: large conductive objects but "thin" and for which the largest dimension is perpendicular to the axis of the gap into which the object is inserted (for example, the transfer of shunt tube during the LW in the substation). The influence of this large conductive object in a gap is presented and an additional method of calculation in the method defined in the IEC 61472 standard is proposed.

1 INTRODUCTION

During live working, conductive objects are brought to penetrate the line-to-ground or line-to-line gaps. While they are not linked to either the ground or the line potential, these conductive objects have a "floating" potential depending on their form, their position in the gap and their electrical environment.

Inserting a conductive object in a gap has two consequences:

- the air gap L_f which ensures insulation is reduced by a certain amount **F** which represents the air gap neutralised by the object, see Figure 1,
- the distribution of potential in the gap is modified in a way that is more or less significant according to the size and the form of the object, see Figure 2.

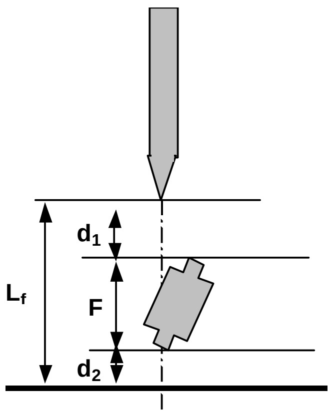

Figure 1: The presence of a conductive object in an interval results in the neutralisation of a part of the air insulation with the length F.

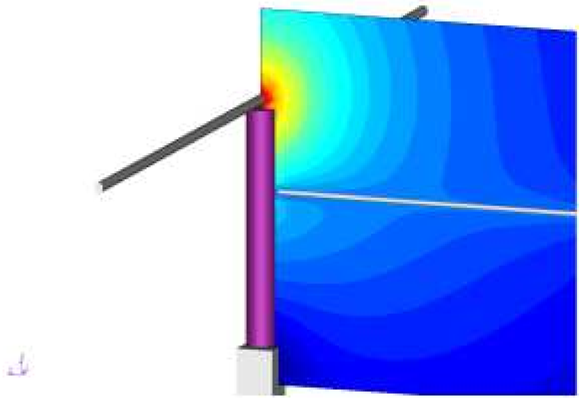

Figure 2: Example of modification by a large size floating object of the repartition of potential around a 225 kV post insulator.

The combination of these two effects generally lead to a reduction in the dielectric strength of the gap. This phenomenon has been the object of several theoretical and experimental studies [1, 2, 3]. The summary of knowledge produced by a CIGRE working group [4, 5] constitutes the basis of the calculation formulas given in the standard IEC 61742 "Live-Working – Minimum approach distances – Method of calculation" [6].

After having recalled the IEC 61472 calculation method, notably the concept of floating object factor k_F we present the test results on an object class, qualified as "thin", for which the method of evaluation of k_F recommended in the standard is not applicable and we propose a calculation formula of k_F which is adapted to thin objects based on the notion of distortion of potential in the gap.

2 THE CONSIDERATION OF FLOATING OBJECTS IN THE STANDARD IEC 61472

Being given $\mathbf{U_{90}}$ the switching overvoltage strength level required for live working (RILL), the standard IEC 61472 defines the withstand minimum electric distance $\mathbf{D_u}$ of an air gap on the basis of the general formula below and taking into consideration the possible presence of a floating object with **F** being its projected dimension:

$$\mathbf{D_U = 2{,}17\,[\,e^{U90\,/\,(1080\,Kt)} - 1\,] + F} \qquad (1)$$

With $\mathbf{K_t = k_g\, k_F\, k_a\, k_s\, k_i}$

- $\mathbf{k_g}$ gap factor
- $\mathbf{k_F}$ floating object factor
- $\mathbf{k_a}$ altitude factor
- $\mathbf{k_s}$ statistical factor (= U_{90}/U_{50})
- $\mathbf{k_i}$ damaged isolator factor

$\mathbf{k_F}$ allows the distortion of the repartition of potential in the gap induced by the floating conductive object to be taken into account; $\mathbf{k_F}$ is weaker than the distortion is significant. The values of $\mathbf{k_F}$ are shown in tabular form in terms of the length of the initial gap $\mathbf{L_f}$ and a parameter of $\boldsymbol{\beta} = \mathbf{F / L_f}$.

Annex F of the standard also presents the calculation chart for the determination of $\mathbf{k_F}$ in terms of $\boldsymbol{\beta}$ and the residual air gap $\mathbf{D = L_f - F}$, see Figure 3. Let us remember that these calculation charts are issued as part of the summary of the results of the tests carried out by the CIGRE group [4, 5], which essentially deal with long objects positioned parallel to the axis of the interval. For this class of objects a weak value of $\boldsymbol{\beta}$, let's say $\boldsymbol{\beta \leq 0.1}$, corresponds to an object said to be an "object with small dimensions" which does not practically create distortion of the repartition of potential and only influences the interval by the neutralised air gap **F**.

It appears, however, as illustrated in fig 2, that there exists objects or the positioning of objects for which $\boldsymbol{\beta \ll 0.1}$, which creates, nevertheless, a strong distortion of the repartition in potential resulting in a reduction in the strength of the interval. Subsequently we will call the objects, which are characterised by a weak value of **ß** but of which at least one of the dimensions in the perpendicular directions to the axis of the interval is great in terms of **F**, "thin conductive objects".

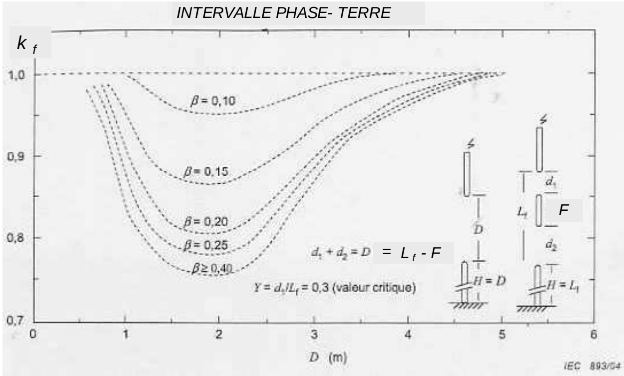

Figure 3: Calculation chart for the determination of the factor of the floating object $\mathbf{k_F}$ in terms of the residual air gap $\mathbf{D = L_f - F}$ for different values of the parameter $\boldsymbol{\beta} = \mathbf{F / L_f}$ - in the case of long objects inserted in a line-to-ground interval (© CEI 61472).

3 TESTS CARRIED OUT WITH VARIOUS THIN CONDUCTIVE OBJECTS

3.1 Tests in an actual LW configuration

The tests carried out are representative of situations encountered during live working in a substation where it is necessary to get close to conductive objects such as a tube (shunt bar), or a plate (conductive carpet used with an insulating platform) neighbouring a post insulator supporting a bus-bar, defining an air gap of characteristics $\mathbf{L_f = 2.1m}$, and $\mathbf{k_g = 1.3}$, see Figure 4.

These objects are "thin" because they have at least a large dimension in a perpendicular plan to the axis of the gap (tube: **3.5m**; plate: **2m x 1m**) and a weak value of **F** (tube: **5cm**, plate: **5mm**).

As indicated in the graph in Figure 4, the thin conductive objects can lead to a significant reduction in the withstand voltage of the gap, notably when they are in a critical position situated at around 40% of $\mathbf{L_f}$ (going from the active electrode), for which the factor of the floating object $\mathbf{k_F = 0.78}$ for the tube and $\mathbf{k_F = 0.83}$ for the plate positioned as in the diagram, $\mathbf{k_F= 0.80}$ for the plate positioned with the little side parallel to the bar. We know that the existence of a critical position is a well-known characteristic of split air gaps [4 ,5].

Our qualitative interpretation of the results observed is that when the floating object, at potential $\mathbf{V_F}$, is in the critical position, the inception voltage of the discharge from the electrode connected to the voltage generator (active electrode) at potential **V** is lower than the difference **$\Delta V = (V - V_F)$** is high, that is to say that **V_F** is low. In consequence, the reduction of potential **V_F** of the object in relation to the value **V_N** of potential in the critical position in the absence of an object (natural potential) results in the reduction of the inception voltage of the gap. This effect can be quantified with the help of a distortion factor of the distribution of potential, written as ϕ and defined as: **$\phi = V_F / V_N$**, see Figure 5.

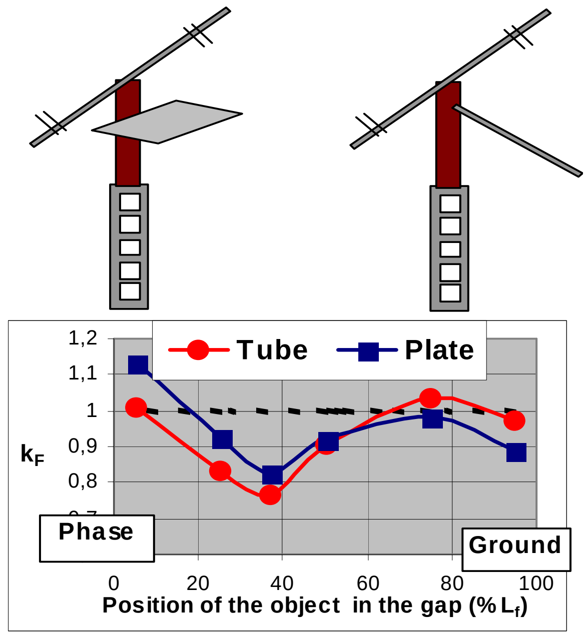

Figure 4: Study using dielectric tests of the influence of thin conductive objects (tube: ∅ = 5 cm, L = 3.5 m; plate: 2 m x 1 m) positioned close to a 225kV post insulator; the characteristics of the gap are: L_f =2.1m; k_g = 1.3.

The distortion factor ϕ is determined by 3D field computation. The values of ϕ as well as the capacitance **C** of the floating object for the different test configurations are given in Table 1.

As can be seen in the last line of Table1, there exists positions of the object for which the distortion of potential is almost inexistent, i.e. **$\phi \sim 1$**, whereas the influence of the object is far to be negligible since in this special case, we get **k_F = 0.83**. This means that ϕ is not the only influential parameter; we guess that the capacitance of the object, in the critical position, also plays a role. Indeed, during the propagation phase of the discharge, before its connection to the object, the potential **V_F** of the object rises because of the collection of charge carriers produced at the head of the discharge, which has a tendency to impede the development of propagation phase of the discharge, before its connection to the object.

Table 1 : Computed ϕ and **C** values for the different test configurations, as well as the corresponding measured values of **k_F**

Configuration	**ϕ**	**C (pF)**	**k_F (measured)**
Plate with small side parallel to the bar	**0.77**	**62**	**0.80**
Plate with large side parallel to the bar	**0.92**	**71**	**0.83**
Tube perpendicular to the bar	**0.62**	**36**	**0.78**
Tube parallel to the bar	**~1**	**52**	**0.83**

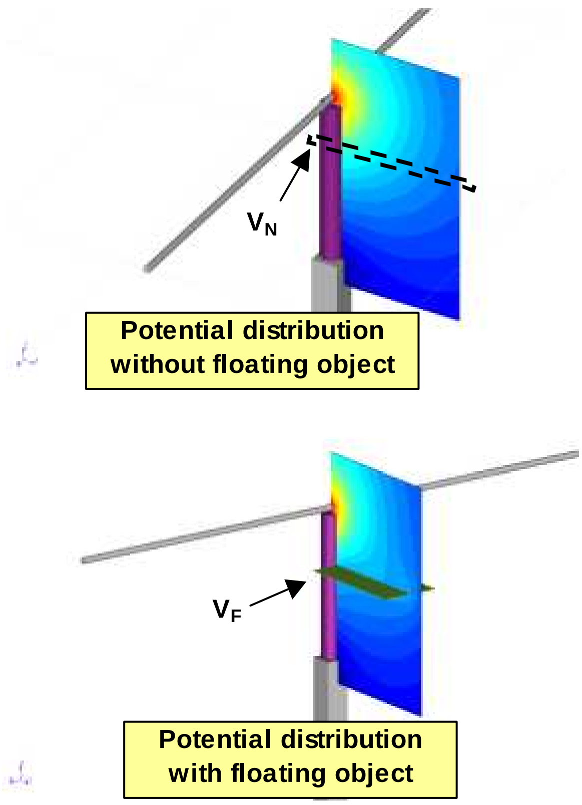

Figure 5: Example of assessment by 3D field computations of the parameter of distortion and of the capacitance of the floating object in the critical position.

However, the increase of $\mathbf{V_F}$, which cannot be totally cancelled out can be limited if the total capacitance **C** of the object has a sufficient value. In addition, the capacitance **C** also determines the electrostatic energy which is storable in the object; it contributes here, if the value is sufficient, to the acceleration of the transition to the arc at the time of the connection to the object (increase of the conductivity of the discharge channel by ohmic heating).

On the basis of this qualitative description, we postulate that the floating object factor $\mathbf{k_F}$ is only dependent on the two variables ϕ and **C**, and that right now it does not depend <u>explicitly</u> on the geometry and the positioning of the object (the geometry and the positioning are taken into account implicitly through the variables ϕ and **C**).

3.2 Tests in 2m rod-plane gap by artificially forcing the potential of the object

The aim of these test is to study the influence of both the potential and the capacitance of the floating object on $\mathbf{k_F}$ under totally controlled conditions. A special test arrangement, as shown Figure 6, allows the potential $\mathbf{V_F}$ of the floating object at the critical position in the gap to be forced at a given value. For a given thin object, plates or tubes of various size, $\mathbf{V_F}$ and **C** cannot be independently changed, however we carried out enough tests with different values of the couple ($\mathbf{V_F}$; **C**) to separately analyse the influence of each of these parameters. The test results are presented Figure 7. It can be seen that, as the potential $\mathbf{V_F}$ is forced - the total capacitance **C** of the object being in this case larger than 100 pF - $\mathbf{k_F}$ linearly varies with ϕ,

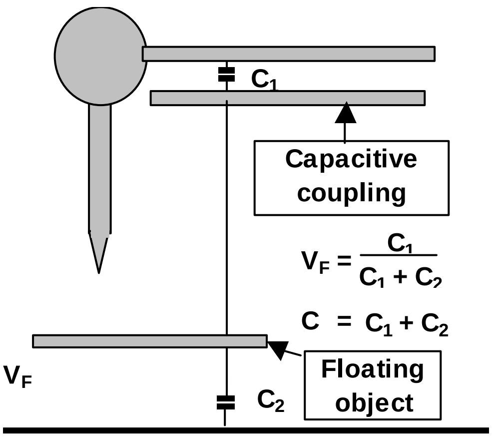

Figure 6: 2 m rod-plane gap with special test arrangement allowing the potential of the floating object (tubes and plates of various size) to be changed from the "free" to a given forced value.

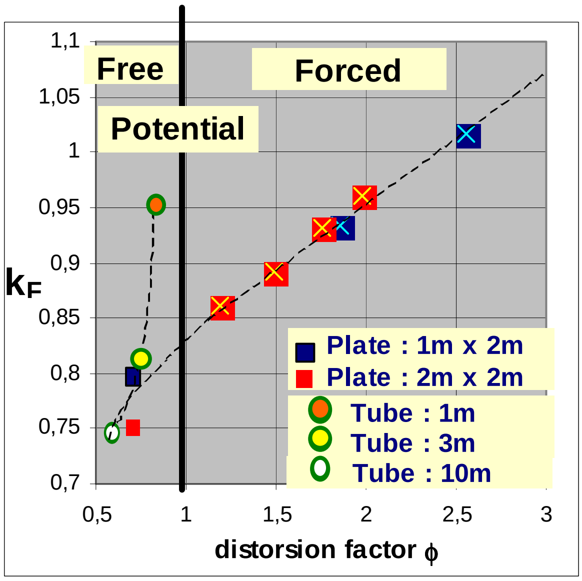

Figure 7: 2 m rod-plane gap with special test arrangement allowing the potential of the floating object (tubes and plates of various size) to be changed from the "free" to a given forced value.

whereas **C** seems to have a minor influence. On the contrary, as the potential $\mathbf{V_F}$ is kept free - the capacitance **C** being in this case lower than 100 pF- we observe a significant influence of **C**.

Such a behaviour suggests ways to derive a formula for the floating object factor $\mathbf{k_F}$ as a function only of ϕ and **C**.

4 DERIVATION OF A FORMULA FOR $\mathbf{k_F}$ APPLICABLE TO THIN OBJECTS

4.1 Research of a simple formula for $\mathbf{k_F}$

The analysis of the test results led us to research a function in the form of: $\mathbf{k_F = a\ \phi + b(\ C\ )}$; the function **b(C)** before responding to the following specifications:

i) **a + b(0) = 1**

ii) **b(C)** is sharply growing by $\mathbf{C \leq C_{min}}$

iii) **b(C)** tends rapidly towards a constant for $\mathbf{C > C_{min}}$

We keep the following form:

$$\mathbf{b(\ C\ ) = A + B\ EXP(-\ C/C_{min}\ )}$$

The adjustment of parameters in the sense of the least squares leads to the formula below (with **C** in **pF**) which is a reasonable compromise between accuracy and simplicity of use:

$$\mathbf{k_F = 0.6 + 0.2\ [\ \phi\ + e^{(-C/35)}\ ]} \qquad \text{.........................(2)}$$

The graph of $\mathbf{k_F(\phi ; C)}$ is shown figure 8.

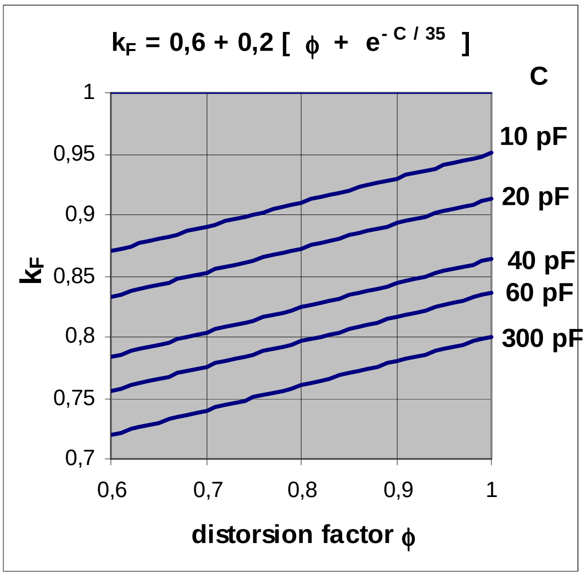

Figure 8: Floating object factor $\mathbf{k_F}$ given by formula (2) as function of the distortion factor ϕ for different capacitance values.

4.2 Assessment of the validity range of Formula (2)

In order to assess the validity range of Formula (2), additional dielectric tests were performed in various configurations of gaps : gap length $\mathbf{L_f}$: 1m, 2m, 3m; gap factor: $\mathbf{k_g}$ = 1, 1.1, 1.3, 1.4, 1.45, see figure 9. In these tests, the floating thin objects were still plates and tubes of different size.

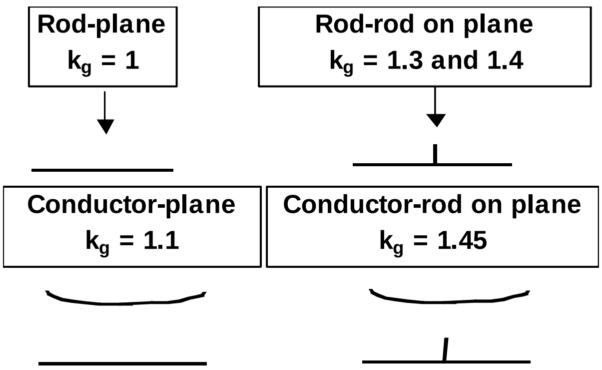

Figure 9: Electrode configurations used for assessing the validity range of Formula (2). For each configuration, the gap length L_f was 1m, 2m, and 3m. The floating thin objects were plates and tubes of various size.

The comparison between calculated values of $\mathbf{k_F}$ by Formula (2) and values issued from dielectric tests is displayed figure 10.

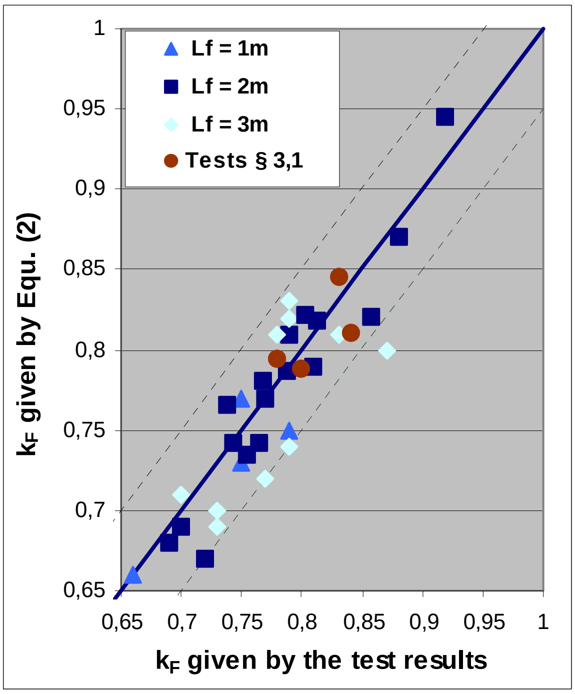

Figure 10: Assessment of the validity range of Formula (2) for the predetermination of the factor of the floating object $\mathbf{k_F}$ applicable to thin objects. The graph regroups all the results of the tests and includes the results presented in section 3.1.

When the scope of validity of this formula is limited to thin objects, the largest dimension $\mathbf{L_{max}}$ (perpendicular to the gap axis) of which satisfying the condition $\mathbf{L_{max} \leq 3\ L_f}$, the range of uncertainty which is **+/- 0.05** at that time, as is shown in the graph in Figure 10.

5 CONCLUSION

Going from the statement that the calculation method of the factor of the floating object $\mathbf{k_F}$ recommended in the standard IEC 61472 [6] is not adapted for the class of objects qualified as "thin", which are characterised by a value of almost zero of the parameter $\boldsymbol{\beta}$, but of which at least one of the dimensions in the perpendicular directions to the interval axis is great in terms of the neutralised air gap **F**, we have researched a new calculation method applicable to thin objects.

The analysis of all the results of our tests involving thin objects of different sizes and forms (plates and tubes) shows that the floating object factor can be expressed in terms of just two parameters $\boldsymbol{\phi}$ and **C**:

ϕ, called the "distortion parameter" is defined as the ratio: $\boldsymbol{\phi = V_F/V_N}$ of the potential $\mathbf{V_F}$ of the object in the critical position, to the potential $\mathbf{V_N}$ of the gap in the same point in the absence of the object,

C is the capacitance of the object in its electric environment.

Knowing that the parameters can be quite easily obtained by calculating the 3D field with the help of softwares which are commercially available, we propose a simple formula for the predetermination of the factor $\mathbf{k_F}$ which is applicable to thin objects of which the maximum dimension $\mathbf{L_{max}}$ satisfies the condition $\mathbf{L_{max} \leq 3\ L_f}$.

6 REFERENCES

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