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INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Live working – Minimum approach distances for a.c. systems in the voltage range 72,5 kV to 800 kV – A method of calculation

Travaux sous tension – Distances minimales d'approche pour des réseaux à courant alternatif de tension comprise entre 72,5 kV et 800 kV – Une méthode de calcul

IEC 61472:2013

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

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LIVE WORKING –
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IN THE VOLTAGE RANGE 72,5 kV TO 800 kV –
A METHOD OF CALCULATION

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International Standard IEC 61472 has been prepared by technical committee 78: Live working.

This third edition cancels and replaces the second edition of IEC 61472 published in 2004. It constitutes a technical revision.

This document has been prepared according to the requirements of IEC 61477: *Live working – Minimum requirements for the utilization of tools, devices and equipment*, where applicable.

Significant changes with regard to the second edition are the following:

– clarification of the scope;
– review of the definitions;
– clarification of the methodology of determining whether live working is permissible and the calculation of the minimum approach distances;

– modification of the basic equation for calculation of the minimum approach distance;
– introduction of Table 1 for altitude correction factor simplification k_a;
– introduction of criteria in presence of composite insulator and clarification on the use of insulator factor k_i;
– review of the informative Annex F on the influence of floating conductive objects on the dielectric strength;
– review of the informative Annex G on live working near contaminated, damaged or moist insulation.

The text of this standard is based on the following documents:

FDIS	Report on voting
78/1004/FDIS	78/1010/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

• reconfirmed,
• withdrawn,
• replaced by a revised edition, or
• amended.

The contents of the corrigendum of October 2015 have been included in this copy.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

LIVE WORKING – MINIMUM APPROACH DISTANCES FOR A.C. SYSTEMS IN THE VOLTAGE RANGE 72,5 kV TO 800 kV – A METHOD OF CALCULATION

1 Scope

This International Standard describes a method for calculating the minimum approach distances for live working, at maximum voltages between 72,5 kV and 800 kV. This standard addresses system overvoltages and the working air distances or tool insulation between parts and/or workers at different electric potentials.

The required withstand voltage and minimum approach distances calculated by the method described in this standard are evaluated taking into consideration the following:

- workers are trained for, and skilled in, working in the live working zone;
- the anticipated overvoltages do not exceed the value selected for the determination of the required minimum approach distance;
- transient overvoltages are the determining overvoltages;
- tool insulation has no continuous film of moisture or measurable contamination present on the surface;
- no lightning is seen or heard within 10 km of the work site;
- allowance is made for the effect of conducting components of tools;
- the effect of altitude, insulators in the gap, etc. on the electric strength is taken into consideration.

For conditions other than the above, the evaluation of the minimum approach distances may require specific data, derived by other calculation or obtained from additional laboratory investigations on the actual situation.

2 Terms, definitions and symbols

For the purpose of this document, the following terms, definitions and symbols apply.

2.1 Terms and definitions

2.1.1
damaged insulator
insulator having any type of manufacturing defect or in-service deterioration which affects its insulating performance

2.1.2
electrical distance
D_U
distance in air required to prevent a disruptive discharge between energized parts or between energized parts and earthed parts during live working

[SOURCE: IEC 60050-651:–, 651-21-12]

2.1.3
ergonomic distance
ergonomic component of distance
D_E
distance in air added to the electrical distance, to take into account inadvertent movement and errors in judgement of distances while performing work

[SOURCE: IEC 60050-651:–, 651-21-13]

2.1.4
fifty per cent disruptive discharge voltage
U_{50}
peak value of an impulse test voltage having a fifty per cent probability of initiating a disruptive discharge each time the dielectric testing is performed

[SOURCE: IEC 60050-604:1987, 604-03-43]

2.1.5
highest voltage of a system
U_s
highest value of operating voltage which occurs under normal operating conditions at any time and any point in the system (phase to phase voltage)

Note 1 to entry: Transient overvoltages due e.g. to switching operations and abnormal temporary variations of voltage are not taken into account.

[SOURCE: IEC 60050-601:1985, 601-01-23, modified – A reference to phase to phase voltage has been added.]

2.1.6
minimum approach distance
minimum working distance
D_A
minimum distance in air to be maintained between any part of the body of a worker, including any object (except tools appropriate for live working) being handled directly, and any part(s) at different electric potential(s)

Note 1 to entry: The minimum approach distance is the sum of the electrical distance appropriate for the maximum nominal voltage and of the selected ergonomic distance.

[SOURCE: IEC 60050-651:–, 651-21-11]

2.1.7
minimum residual insulation length
D_{Lins}
insulation length required to prevent a disruptive discharge between energized parts and earthed parts measured along the insulator length, taking into account the presence of floating conductive objects and of damaged insulator portions

2.1.8
ninety per cent statistical impulse withstand voltage
U_{90}
peak value of an impulse test voltage at which insulation exhibits, under specified conditions, a ninety per cent probability of withstand

Note 1 to entry: This concept is applicable to self-restoring insulation.

[SOURCE: IEC 60050-604:1987, 604-03-42, modified – The definition has been changed to refer specifically to a ninety per cent probability of withstand.]

2.1.9
part
any element present in the work location, other than workers, live working tools and system insulation

2.1.10
per unit value
u
expression of the per unit value of the amplitude of an overvoltage (or of a voltage) referred to $U_s\sqrt{2}/\sqrt{3}$

Note 1 to entry: This applies to u_{e2} and u_{p2} defined in Clause 4.

2.1.11
transient overvoltage
short duration overvoltage of few milliseconds or less, oscillatory or non-oscillatory, usually highly damped

[SOURCE: IEC 60050-604:1987, 604-03-13, modified – The two notes in the original definition have been deleted.]

2.1.12
two per cent statistical overvoltage
$\boldsymbol{U_2}$
peak value of a transient overvoltage having a 2 per cent statistical probability of being exceeded

2.1.13
work location
any site, place or area where a work activity is to be, is being, or has been carried out

[SOURCE: IEC 60050-651:–, 651-26-03]

2.2 Symbols used in the normative part of the document

A_d	length of damaged insulator or number of damaged units in an insulator of length A_o, not shunted by long arcing horn or grading ring
A_o	length of undamaged insulator or number of undamaged insulator units not shunted by long arcing horn or grading ring
β	ratio of the total length in the direction of the gap axis of the floating conductive objects (s) to the original air gap length
D	length of the remaining air gap phase to earth
D_A	minimum approach distance
D_E	ergonomic distance
D_U	electrical distance necessary to obtain U_{90}
D_{Lins}	minimum residual insulation length
d_1, d_2, d_3, d_4	distances between the worker(s) and parts of the installation at different electric potentials (see Figure 2)
F	sum of all lengths, in the direction of the gap axis, of all floating conductive objects in the air gap (in metres)

K_s statistical safety factor

K_t factor combining different considerations influencing the strength of the gap

k_a atmospheric factor

k_d coefficient characterizing the average state of the damaged insulators

k_f floating conductive object factor

k_g gap factor

k_i damaged insulator factor

k_{ic} damaged composite insulator factor

k_{is} damaged insulator strings factor

k_s standard statistical deviation factor

L_f original air gap length

P length of the remaining gap phase to phase

r distance of a conductive object from the axis of the gap

s_e normalized value of the standard deviation of U_{50} expressed in per cent

U_2 two per cent statistical overvoltage

U_{50} fifty per cent disruptive discharge voltage

U_{90} ninety per cent statistical impulse withstand voltage

U_{e2} two per cent statistical overvoltage between phase and earth

U_{e90} ninety per cent statistical impulse withstand voltage phase to earth

U_{p2} two per cent statistical overvoltage between two phases

U_{p90} ninety per cent statistical impulse withstand between two phases

u_{e2} per unit value of the two per cent statistical overvoltage phase to earth

u_{p2} per unit value of the two per cent statistical overvoltage between two phases

U_s highest voltage of a system between two phases

3 Methodology

The methodology of determining whether live working is permissible and the calculation of the minimum approach distances is based on the following considerations:

a) to determine the statistical overvoltage expected in the work location (U_2) and from this, determine the required statistical impulse withstand voltage of the insulation in the work location (U_{90});
b) to calculate the minimum residual insulation length D_{Lins} if working next to insulators;
c) to calculate the electrical distance D_U required for the impulse withstand voltage U_{90};
d) to add an additional distance to allow for ergonomic factors associated with live working, such as inadvertent movement.

The minimum approach distance D_A is thus determined by:

$$D_{\mathrm{A}} = D_{\mathrm{U}}(K_s = 1{,}0) + D_{\mathrm{E}} \tag{1}$$

where

D_{U} is the electrical distance necessary to obtain U_{90};

D_{E} is the ergonomic distance and is dependent on work procedures, level of training, skill of the workers, type of construction, and such contingencies as inadvertent movement, and errors in appraising distances (see Annex A for details).

Refer to Clause 5 for application of ergonomic distance.

4 Factors influencing calculations

4.1 Statistical overvoltage

The electrical stress at the work location shall be known. The electrical stress is described as the statistical overvoltage that may be present at the work location. In a three-phase a.c. power system the statistical overvoltage U_{e2} between phase and earth is:

$$U_{\mathrm{e2}} = (\sqrt{2}/\sqrt{3})\ U_{\mathrm{s}}\ u_{\mathrm{e2}} \tag{2}$$

where

U_{s} $(\sqrt{2}/\sqrt{3})$ is the highest phase to earth peak voltage, of the system expressed in kV, and u_{e2} is the statistical overvoltage phase to earth expressed in per unit.

The statistical overvoltage U_{p2} between two phases is:

$$U_{\mathrm{p2}} = (\sqrt{2}/\sqrt{3})\ U_{\mathrm{s}}\ u_{\mathrm{p2}} \tag{3}$$

where u_{p2} is the statistical overvoltage phase to phase expressed in per unit.

If the per unit phase to phase data are not available, an approximate value can be derived from u_{e2} by the following formula:

$$u_{\mathrm{p2}} = 1{,}35\ u_{\mathrm{e2}} + 0{,}45 \tag{4}$$

The transient overvoltages to be considered are the maximum that can occur, either on the installation being worked on or at the work site, whether caused by system faults or by switching (see Annex B).

4.2 Gap strength

For the determination of the electrical distance, the required withstand voltage for live working is taken to be equal to the voltage U_{90}, determined from the general expression

$$U_{90} = K_{\mathrm{s}}\ U_2 \tag{5}$$

Considering the phase to earth and phase to phase voltages separately and combining equation (5) with equations (2) and (3) gives:

$$U_{\mathrm{e90}} = K_{\mathrm{s}}\ (\sqrt{2}/\sqrt{3})\ U_{\mathrm{s}}\ u_{\mathrm{e2}} \tag{6}$$

$$U_{\mathrm{p90}} = K_{\mathrm{s}}\ (\sqrt{2}/\sqrt{3})\ U_{\mathrm{s}}\ u_{\mathrm{p2}} \tag{7}$$

where

K_s is the statistical safety factor (1,0 or 1,1 for formula (5), (6) and (7)) (see Clause 5);

U_{e90} and U_{p90} are respectively the statistical impulse withstand voltages phase to earth and phase to phase, expressed in kV.

4.3 Calculation of electrical distance DU

4.3.1 General equation

The strength of the gap is influenced by a series of considerations which can be combined in a factor K_t used in the following formula for calculating D_U (in metres):

$$D_U = 2{,}17\ (e^{U_{90}/(1\,080 K_t)} - 1) + F \tag{8}$$

where

F sum of all lengths, in the direction of the gap axis, of all floating conductive objects in the air gap (in metres) (see 4.3.2.4);

U_{90} is the phase to earth (U_{e90}) or the phase to phase (U_{p90}) statistical impulse withstand voltage in kV;

K_t is given by:

$$K_t = k_s\, k_g\, k_a\, k_f\, k_i \tag{9}$$

4.3.2 Factors affecting gap strength

4.3.2.1 Standard statistical deviation factor k_s

Factor k_s accounts for the statistical nature of the breakdown voltage. Unless the value of the standard deviation, s_e, is known from tests representing the gap configuration, a value of 0,936, based on a standard deviation of 5 %, for positive impulses, can be used (see Annex C).

4.3.2.2 Gap factor k_g

The gap factor k_g takes into account the effect of the gap configuration on the dielectric strength of air (see Annex D).

NOTE 1 Unless an appropriate gap factor can be selected for the structure configurations that exist at the system voltage being considered, a generally conservative value that allows for a variety of configurations is k_g = 1,2 for phase to earth and k_g = 1,45 for phase to phase.

NOTE 2 CIGRÉ Brochure 72 and IEC 60071-2 provide more information concerning the determination of k_g for various gap configurations.

4.3.2.3 Atmospheric factor k_a

The atmospheric factor takes into account the effect of air density. Air density is influenced by temperature, humidity and altitude. The effect of temperature and humidity is negligible in comparison with the effect of altitude.

The electric strength of the air insulation in the work location is mainly affected by the altitude above sea level. This effect, which varies to some extent with the gap length, or conversely with the withstand voltage, is accounted for by the atmospheric factor k_a. The appropriate value of k_a can be selected from Table 1 of average values or from Table E.1 or calculated for a specific altitude and U_{90} by the method given in Annex E, for a reference altitude below which most live work is done.

Table 1 – Average k_a values

Altitude m	k_a average
0	1,000
100	0,995
300	0,983
500	0,972
1 000	0,941
1 500	0,909
2 000	0,875
2 500	0,841
3 000	0,805

The electrical distance D_U should be increased when live work is carried out in locations higher than the reference altitude in order to account for the lower mean atmospheric pressure. This can be done by multiplying D_U by an altitude correction factor, which can be calculated using the equations given in Annex E.

4.3.2.4 Floating conductive object factor k_f

Floating conductive objects can decrease, or increase, the electric strength of a gap by field distortion.

A conductive object placed between two electrodes at different electric potentials, and not connected to either one, is electrically floating and acquires an intermediate potential. The extent of the influence these floating conductive objects have on the electric strength of the gap varies depending on the number of floating conductive objects, their dimensions, shapes and geometrical positions in the gap. Nevertheless, the presence of the floating conductive object(s) reduces the net electrical length of the air gap.

When calculating the effects of floating conductive objects, all possible disruptive discharge paths should be considered in determining the floating conductive object factor k_f. The sum of all floating conductive objects in the direction of the gap axis constitutes the floating conductive object length, F.

In the most common live line work situations on high voltage lines, the k_f factor depends on the length of the remaining gap and on the lateral distance r of the conductive object from the axis of the gap (see Figure 1). It has to be pointed out that D is obtained by subtracting the length F from the original air gap L_f, i.e. $D = L_f - F$. Annex F provides evaluation criteria of the k_f factor as a function of F and D (P when phase to phase distances are considered), by introducing the parameter

$$\beta = F/(D+F)$$

(or $\beta = F/(P+F)$ when phase to phase distances are considered).

Experimental investigations (see Annex F) have shown that, in the more critical cases representative of live line working configurations, the k_f coefficient may be as low as 0,75 for phase to earth gap distances over 1,2 m.

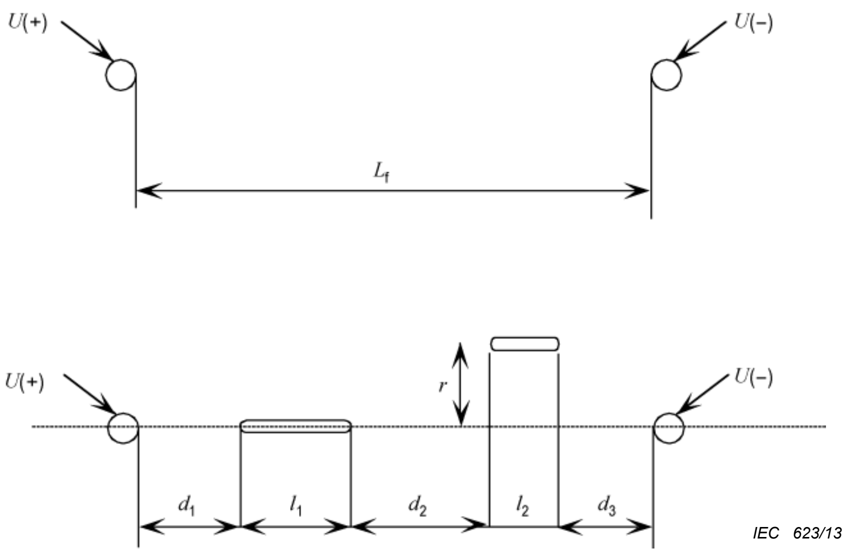

Figure 1 – Illustration of two floating conductive objects of different dimensions and at different distances from the axis of the gap

Table 2 reports a simplified criterion for the k_f determination in dependence of β and L_f. The k_f values are derived from the interpolation of the data shown in Annex F. Table 2 contains the values of β in function of the original gap length L_f rather than in function of the remaining air gap length D because the original gap length L_f is one of the important quantities that characterise the constructed a.c. system.

For long or flat shaped conductive objects situated perpendicular to the air gap, for which no specific experimental data exists, a conservative value k_f = 0,75 may be assumed.