

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

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee PEL/78, Tools for live working, which has the responsibility to:

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**Live working –
Minimum approach distances for a.c. systems
in the voltage range 72,5 kV to 800 kV –
A method of calculation
(IEC 61472:2004)**

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
(CEI 61472:2004)

Arbeiten unter Spannung –
Mindest-Arbeitsabstände für
Wechselspannungsnetze im
Spannungsbereich von 72,5 kV
bis 800 kV –
Berechnungsverfahren
(IEC 61472:2004)

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CENELEC

European Committee for Electrotechnical Standardization
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Foreword

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The following dates were fixed:

- | | | |
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| – latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement | (dop) | 2005-07-01 |
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Endorsement notice

The text of the International Standard IEC 61472:2004 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60060-1	NOTE	Harmonized as HD 588.1 S1:1991 (not modified).
IEC 60071-1	NOTE	Harmonized as EN 60071-1:1995 (not modified).
IEC 60071-2	NOTE	Harmonized as EN 60071-2:1997 (not modified).
IEC 60743	NOTE	Harmonized as EN 60743:2001 (not modified).
IEC 61477	NOTE	Harmonized as EN 61477:2002 (not modified).

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LIVE WORKING – MINIMUM APPROACH DISTANCES FOR AC 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 between parts and/or workers at different 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 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 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

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

[IEV 601-01-23, modified]

2.1.2

transient overvoltage

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

[IEV 604-03-13]

2.1.3

fifty per cent disruptive discharge voltage

U_{50}

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

[IEV 604-03-43]

2.1.4

ninety per cent statistical impulse withstand voltage

U_{90}

peak value of an impulse test voltage at which insulation exhibits, under specified conditions, a 90 % probability of withstand

NOTE This concept is applicable to self-restoring insulation.

[IEV 604-03-42, modified]

2.1.5

two per cent statistical overvoltage

U_2

peak value of a transient overvoltage having a 2 % statistical probability of being exceeded

[IEV 651-01-23, modified]

2.1.6

required insulation level for live working

statistical impulse withstand voltage of the insulation at the work location necessary to reduce the risk of breakdown of this insulation to an acceptably low level

NOTE It is generally considered that an acceptable low level is reached when the value of the statistical withstand voltage is greater or equal to the statistical overvoltage having a probability of being exceeded by no more than 2 %.

[IEV 651-01-17]

2.1.7

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 This applies to u_{e2} and u_{p2} defined in Clause 4.

2.1.8

minimum approach distance

D_A

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

NOTE The “appropriate tools” are tools for live working suitable for the maximum nominal voltage of the live parts.

[Definition 2.7.1 of IEC 60743 and IEC 651-01-20, modified]

2.1.9

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

[Definition 2.7.2 of IEC 60743 and IEC 651-01-21, modified]

2.1.10 ergonomic distance

D_E

distance in air to take into account inadvertent movement and errors in judgement of distances while performing work

[Definition 2.7.3 of IEC 60743 and IEC 651-01-22]

2.1.11

part

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

2.1.12

live part

conductor or conductive part intended to be energized in normal operation, including a neutral conductor, but by convention not a PEN conductor [IEV 195-02-12] or PEM conductor [IEV 195-02-13] or PEL conductor [IEV 195-02-14]

NOTE This concept does not necessarily imply a risk of shock.

[Definition 2.1.2 of IEC 60743 and IEC 651-01-03, modified]

2.1.13

work location

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

[IEV 651-01-08]

2.2 Symbols used in the normative part of the document

β	ratio of the total length of the floating object(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_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 dimensions, in the direction of the gap axis, of the floating 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 units
k_f	floating object factor
k_g	gap factor

k_i	insulator strings factor
k_s	standard statistical deviation factor
L_f	original air gap length
n_d	number of damaged units in a string of n_o units
n_o	number of units in an insulator string that are not shunted by arcing horns or grading rings
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 percent
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 the calculation of the minimum approach distances is based on three considerations:

- 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});
- to calculate the electrical distance D_U required for the impulse withstand voltage U_{90} ;
- 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:

$$D_A = D_U + D_E \quad (1)$$

where

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

D_E is the required 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).

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:

$$U_{e2} = (\sqrt{2}/\sqrt{3}) U_s u_{e2} \quad (2)$$

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:

$$U_{p2} = (\sqrt{2}/\sqrt{3}) U_s u_{p2} \quad (3)$$

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:

$$u_{p2} = 1,35 u_{e2} + 0,45 \quad (4)$$

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

$$U_{90} = K_s U_2 \quad (5)$$

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

$$U_{e90} = K_s (\sqrt{2}/\sqrt{3}) U_s u_{e2} \quad (6)$$

$$U_{p90} = K_s (\sqrt{2}/\sqrt{3}) U_s u_{p2} \quad (7)$$

where

K_s is the statistical safety factor (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 D_U

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):

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

where

F is the floating object distance in metres (see 4.3.4);

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

K_t is given by:

$$K_t = k_s k_g k_a k_f k_i \quad (9)$$

4.3.1 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 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 of $k_g = 1,2$ for phase to earth and $k_g = 1,45$ for phase to phase are recommended, to allow for a variety of configurations.

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

4.3.3 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 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.

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.

4.3.4 Floating object factor k_f

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

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

When calculating the effects of floating objects, all possible disruptive discharge paths should be considered in determining the object factor k_f and a floating object distance F (sum of all dimensions, in the direction of the gap axis, of the floating objects in the air gap).

The k_f factor depends on the dimension F of the conductive floating object in the direction of the axis of the gap, on the length D of the remaining gap and on the lateral distance r of the conductive object from the axis of the gap (see Figure 1). It must be pointed out that D is obtained by subtracting the length F from the original air gap L_f , i.e. $D = L_f - F$. Papers of international level (see Annex F) provide 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).

These studies and other experimental investigations 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.

Table 1 reports a simplified criterion for the k_f determination in dependence of β and L_f . The k_f values derive from the interpolation of the data shown in Annex F. Table 1 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.

Table 1 – Floating object factor k_f

Phase to earth gaps						Phase to phase gaps					
β^{**}	L_f^* m				k_f	β^{**}	L_f^* m				k_f
	Over	Up to	Over	Up to			Over	Up to	Over	Up to	
0,1	---	0,9	3,9	---	1	0,05	---	0,9	5,7	---	1
	0,9	3,9	---		0,95		0,9	2,1	3,8	5,7	0,95
0,15	---	0,5	4,7	---	1		0,1	2,1	3,8	---	
	0,5	1	3,3	4,7	0,95	---		0,6	6	---	1
	1	1,2	2,7	3,3	0,9	0,6		1,6	4,6	6	0,95
	1,2	2,7	---		0,85	1,6		2,2	3,6	4,6	0,9
0,2	---	0,4	4,9	---	1	2,2		3,6	---		0,85
	0,4	0,9	3,7	4,9	0,95	0,2	---	0,4	6,3	---	1
	0,9	1	3,1	3,7	0,9		0,4	1,4	5,1	6,3	0,95
	1	1,2	2,6	3,1	0,85		1,4	1,8	4,4	5,1	0,9
	1,2	2,6	---		0,8		1,8	2,3	3,5	4,4	0,85
0,25	---	0,3	5,1	---	1		2,3	3,5	---		0,8
	0,3	0,8	3,8	5,1	0,95	Over 0,35	---	0,2	6,6	---	1
	0,8	0,9	3,2	3,8	0,9		0,2	1,2	5,3	6,6	0,95
	0,9	1,1	2,8	3,2	0,85		1,2	1,6	4,6	5,3	0,9
	1,1	1,3	2,4	2,8	0,8		1,6	2,1	3,8	4,6	0,85
	1,3	2,4	---		0,75		2,1	3,8	---		0,8
Over 0,40	---	0,2	5,3	---	1						
	0,2	0,7	3,8	5,3	0,95						
	0,7	0,8	3,2	3,8	0,9						
	0,8	1	2,9	3,2	0,85						
	1	1,2	2,6	2,9	0,8						
	1,2	2,6	---		0,75						

* L_f = Original air gap length.

** β = Ratio of the total length of the floating object(s) to the original air gap length.

As far as the influence of the distance of the floating objects from the axis of the gap is considered, it may be assumed that the reduction of the electric strength becomes negligible when

$$r > 2,5 F$$

The influence of metallic caps and pins of suspension insulators is negligible and shall be ignored.

The approach in Annex F gives general criteria for the determination of k_f . The real influence of the floating objects requires a detailed analysis (see Annex F).

Figure 2 illustrates various distinct live working tasks and the configurations in which they can occur. According to the considered configuration, a correct value of k_g and k_f should be determined.

See Annex F for more details.