

NATIONAL STANDARD OF CANADA NORME NATIONALE DU CANADA

CAN/ULC-61472-14 (CEI/IEC 61472:2013, IDT)

La norme internationale **CEI/IEC 61472:2013, (troisième édition, 2013-04)** a été adoptée sans les exigences propres au Canada (IDT) et porte la désignation **CAN/ULC-61472-14** la première édition. Elle a été approuvée comme Norme nationale du Canada par le Conseil canadien des normes.

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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

ICS 13.260, 29.240.20, 29.260.99

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

ICS 13.260, 29.240.20, 29.260.99



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International Electrotechnical Commission**

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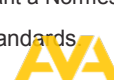
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NORME NATIONALE DU CANADA

NATIONAL STANDARD OF CANADA

CAN/ULC-61472-14
(CEI/IEC 61472:2013, IDT)

**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**

ICS 13.260, 29.240.20, 29.260.99

CAN/ULC-61472-14
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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**

ICS 13.260, 29.240.20, 29.260.99

Préparée par / Prepared by
**International Electrotechnical Commission
Commission Électrotechnique Internationale**



Passé en revue par / Reviewed by
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Normes ULC**



Approuvée par le / Approved by



**Standards Council of Canada
Conseil canadien des normes**

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CAN/ULC-61472-14

(CEI/IEC 61472:2013, IDT)

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

PRÉFACE ULC

Ce document constitue la première édition de la norme, CAN/ULC-61472-14 (CEI/IEC 61472:2013, IDT), 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, laquelle constitue une adoption de la norme internationale de la Commission Électrotechnique Internationale, CEI/IEC 61472 (troisième édition, 2013-04)

Au Canada, il y a deux langues officielles, le français et l'anglais. Tous les avertissements de sécurité doivent être en français et en anglais. Il importe de signaler que certaines autorités canadiennes peuvent exiger que des marquages et/ou des directives d'installation supplémentaires soient dans les deux langues officielles.

Cette édition de la norme a été approuvée par le Comité ULC sur les travaux sous tension et a été approuvée en tant que Norme nationale du Canada par le Conseil canadien des normes.

La révision de cette norme débutera dans les 5 ans suivant la date de publication, à moins que la norme soit désignée comme entrant dans une catégorie stabilisée, auquel cas la révision commencera dans le délai approprié défini par Normes ULC.

La présente norme est destinée à être utilisée à des fins d'évaluation de la conformité.

Une grande partie du financement nécessaire au processus d'adoption de cette norme nationale du Canada a été assurée par l'association canadienne de l'électricité (ACE) que nous tenons à remercier.

Mai 2014

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CAN/ULC-61472-14

(CEI/IEC 61472:2013, IDT)

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

ULC PREFACE

This is the First Edition of the Standard CAN/ULC-61472-14 (CEI/IEC 61472:2013, IDT), Live working – Minimum approach distances for a.c. systems in the voltage range 72,5 kV to 800 kV – A method of calculation, which is an adoption of the international standard by International Electrotechnical Commission, CEI/IEC 61472:2013 (Third Edition 2013-04).

In Canada there are two official languages, English and French. All safety warnings must be in French and English. Attention is drawn to the possibility that some Canadian authorities may require additional markings and/or installation instructions to be in both official languages.

This Edition of the Standard has been formally approved by the ULC Committee on Live Working and has been approved as a National Standard of Canada by the Standards Council of Canada.

The initiation of the review of this Standard will commence within 5 years of the date of publication, unless the Standard is identified as fitting within a stabilized category, whereby the review will commence within the appropriate time frame set out by ULC Standards.

This Standard is intended to be used for conformity assessment.

Major funding in support of the adoption process of this National Standard of Canada was provided by the Canadian Electricity Association (CEA), whose assistance is acknowledged with thanks.

May 2014

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INTERNATIONAL STANDARD

NORME INTERNATIONALE

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



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CONTENTS

FOREWORD	4
1 Scope	6
2 Terms, definitions and symbols	6
2.1 Terms and definitions	6
2.2 Symbols used in the normative part of the document	8
3 Methodology	9
4 Factors influencing calculations	10
4.1 Statistical overvoltage	10
4.2 Gap strength	10
4.3 Calculation of electrical distance D_U	11
4.3.1 General equation	11
4.3.2 Factors affecting gap strength	11
5 Evaluation of risks	16
6 Calculation of minimum approach distance D_A	17
Annex A (informative) Ergonomic distance	18
Annex B (informative) Overvoltages	20
Annex C (informative) Dielectric strength of air	24
Annex D (informative) Gap factor k_g	26
Annex E (informative) Allowing for atmospheric conditions	28
Annex F (informative) Influence of floating conductive objects on the dielectric strength	32
Annex G (informative) Live working near contaminated, damaged or moist insulation	40
Bibliography	45
Figure 1 – Illustration of two floating conductive objects of different dimensions and at different distances from the axis of the gap	13
Figure 2 – Typical live working tasks	15
Figure B.1 – Ranges of u_{e2} at the open ended line due to closing and reclosing according to the type of network (meshed or antenna) with and without closing resistors and shunt reactors	22
Figure F.1 – Influence of the length of the floating conductive objects – phase to earth rod-rod configuration – 250 μ s / 2 500 μ s impulse	35
Figure F.2 – Influence of the length of the floating conductive objects – phase to phase conductor-conductor configuration – 250 μ s / 2 500 μ s impulse	36
Figure F.3 – Reduction of the dielectric strength as a function of the length D for constant values of β – Phase to earth rod-rod configuration	37
Figure F.4 – Reduction of the dielectric strength as a function of the length P for constant values of β – Phase to phase conductor-conductor configuration	37
Figure G.1 – Strength of composite insulators affected by simulated conductive and semi-conductive defects	43
Table 1 – Average k_a values	12
Table 2 – Floating conductive object factor k_f	14
Table B.1 – Classification of overvoltages according to IEC 60071-1	20

Table D.1 – Gap factors for some actual phase to earth configurations 27

Table E.1 – Atmospheric factor k_a for different reference altitudes and values of U_{g0} 30

Table G.1 – Example of maximum number of damaged insulators calculation (gap factor 1,4) 41

Table G.2 – Example of maximum number of damaged insulators calculation (gap factor 1,2) 42

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

FOREWORD

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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.

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

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:

- 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 minimum residual insulation length D_{Lins} if working next to insulators;
- 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:

$$D_A = D_U(K_s = 1,0) + D_E \quad (1)$$

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:

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

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 (1,0 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 D_U

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):

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

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:

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

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.

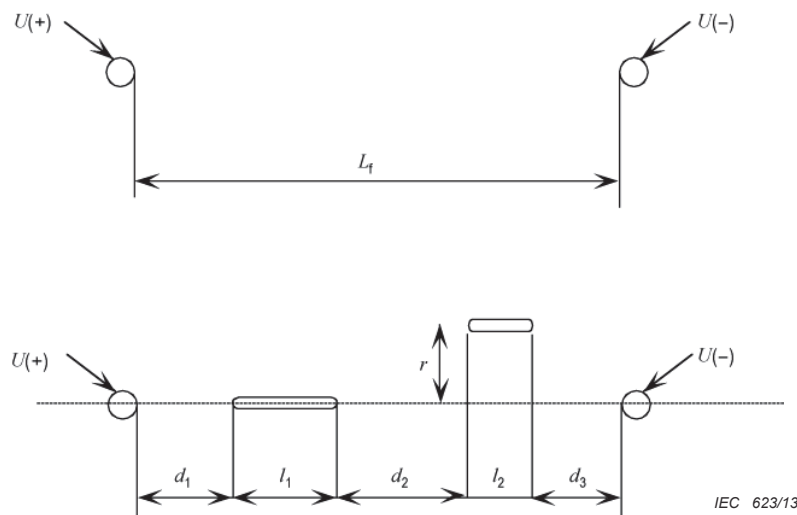


Figure 1 – Illustration of two floating conductive objects of different dimensions and at different distances from the axis of the gap

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.

Table 2 – Floating conductive object factor k_f

Phase to earth gaps						Phase to phase gaps					
β^b	L_f^a m				k_f	β^b	L_f^a 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		2,1	3,8	---		0,9
	0,5	1	3,3	4,7	0,95	0,1	---	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						
	0,8	0,9	3,2	3,8	0,9						
	0,9	1,1	2,8	3,2	0,85						
	1,1	1,3	2,4	2,8	0,8						
	1,3	2,4	---		0,75						
NOTE When β values over the ones tabulated are involved, tests or studies are needed in order to consider the actual floating conductive object shape and dimension.											
^a L_f = Original air gap length.											
^b 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.											

As far as the influence of the distance of the floating conductive 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 and conductive objects of similar size, in the vicinity of the insulators, is negligible and shall be ignored.

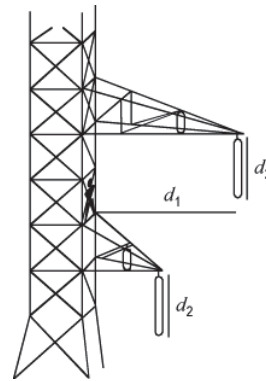
The approach in Annex F gives general criteria for the determination of k_f . The real influence of the floating conductive objects requires a detailed analysis (see Annex F).

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.

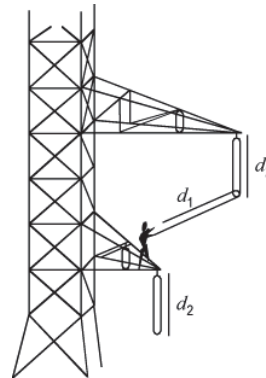
a) Worker not in the air gap

$$d_1 > D_A$$



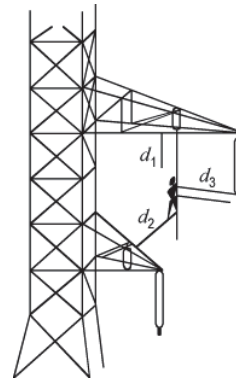
b) Worker using insulating stick

$$d_1 > D_A$$

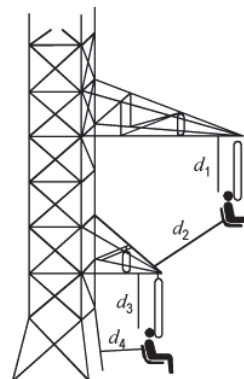


c) Worker at intermediate potential
The smallest distance between

$$d_1 + d_3 \text{ or } d_2 + d_3 > D_A$$



d) Barehand work
The smallest distance between
 d_1 or d_2 and d_3 or $d_4 > D_A$



IEC 624/13

Figure 2 – Typical live working tasks

4.3.2.5 Damaged insulator factor k_i

When working next to insulators it is necessary to calculate the minimum residual insulation length, D_{Lins} . This is done taking into account the effects of damaged insulators or portion of damaged insulator on the minimum approach distance (refer to Clause 3 for the methodology).

Care shall be taken that the electrical integrity of the insulator assembly is not impaired by tools in parallel, moisture or contamination on the surface and damaged insulators (see Annex G).

The effect of damaged insulation on the withstand voltage in the work location shall be considered by ensuring that a minimum number of undamaged insulator units or insulator length is present before commencing work. The minimum residual insulation length, D_{Lins} , shall be determined from equation (10) using K_t as given in equation (11) and a value of k_i given in the empirically-derived formula (12). The residual insulation length may otherwise be determined from test data or by other means.

$$D_{Lins} = 2,17 (e^{U_{90}/(1\ 080\ K_t)} - 1) + F \quad (10)$$

where

$$K_t = k_s k_g k_a k_f k_i \quad (11)$$

$$k_i = 1 - 0,8 k_d (A_d/A_o) \quad (12)$$

where

A_o is the length of undamaged insulator or number of undamaged insulator units not shunted by long arcing horn or grading ring;

A_d is the length of damaged insulator or number of damaged units in an insulator of A_o length or units not shunted by long arcing horn or grading ring;

k_d is a coefficient characterizing the average state of the damaged units;

$k_d = 1$ for toughened glass insulators;

$k_d = 0$ to 1 for porcelain insulators, with $k_d = 0,75$ as an average value;

$k_d = 1,25$ for composite insulators affected by conductive or semiconductive damages (see Annex G).

Refer to Annex G for consideration of arcing horn or grading ring spacing.

NOTE Portions of insulators shielded by horns or rings do not significantly contribute to the dielectric strength of the string, hence damage in this area is less important and these portions can be shorted during work.

5 Evaluation of risks

The overall risk of breakdown of the insulation at the work location is associated with a number of situations described below. These situations, when combined, reduce the overall risk of breakdown. They are as follows:

- the actual system voltage is not always at a maximum value;
- the location of the work is not likely to correspond to the place where a transient overvoltage is at the maximum value;
- the stress of the actual transient overvoltage wavefront is less than the critical front;

- approximately half of the transient overvoltages will be of negative polarity, and are less severe;
- the frequency and amplitude of transient overvoltages are reduced by restricting reclosing of circuit breakers.

Thus, when no ergonomic distance is used, the value of 1,1 is recommended for K_s to reduce the overall risk of breakdown of the insulation to a level that correlates with other electrical work operations.

The overall risk of a breakdown occurring during live working, when an ergonomic distance D_E is incorporated, will be lower because an overvoltage is unlikely to arise at the work location at that instant where the ergonomic distance is entirely breached by inadvertent movement of the worker or object. Because of this, a value of $K_s = 1,0$ can be used when a defined ergonomic distance D_E is included and is great enough that the value of D_A is always greater than the value of D_A (when D_E is zero) with D_U calculated using $K_s = 1,1$ i.e.:

$$D_A = D_{U(K_s = 1,0)} + D_E > D_{U(K_s = 1,1)}$$

where $D_{U(K_s = 1,0)}$ and $D_{U(K_s = 1,1)}$ are D_U calculated using $K_s = 1,0$ and $K_s = 1,1$ respectively.

6 Calculation of minimum approach distance D_A

The following example is provided for demonstrating the use of equation (8) only and does not suggest proper or typical selection of k values, u_{e2} , or other factors.

The electrical distance D_U is calculated (in metres) from:

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

where

F is the floating conductive object length (see 4.3.2.4);

$U_{90} = K_s U_2$ (from equation (5));

K_t is obtained in equation (9) $K_t = k_s k_g k_a k_f k_i$.

After selecting an appropriate value for the ergonomic distance D_E (see Clause 5 and Annex A), the minimum approach distance D_A can then be determined by equation (1):

$$D_A = D_{U(K_s=1,0)} + D_E$$

NOTE The value chosen for the ergonomic distance differs between users. It generally falls in the range of 0,2 m to 1 m (see Clause 5 and Annex A).

In this example, electrical distance D_U is calculated for $K_s = 1,0$; $k_s = 0,936$; $k_g = 1,2$; $k_a = 0,941$ (from Table 1 for 1 000 m); k_f and $k_i = 1,0$, $U_s = 525$ kV, $u_{e2} = 2,2$, $F = 0$ and $D_E = 0,3$ m.

$$D_U = 2,787 \text{ m (2,8 m)}$$

$$D_A = 2,8 \text{ m} + 0,3 \text{ m} = 3,1 \text{ m}$$

Annex A (informative)

Ergonomic distance

A.1 Overview

Two approaches, or a blend of both, can be used to establish an ergonomic distance:

- specify only an absolute minimum approach distance and let the skilled worker decide the extra distance required for the particular job to be done;
- specify a complete minimum approach distance allowing a sufficient safety margin to account for all possible contingencies.

A number of factors have to be considered before specifying the minimum approach distance, or commencing work close to a live conductor. As it is impractical and inappropriate to recommend an ergonomic distance here, the following points are provided as guidelines for consideration by individual organisations.

A.2 Training, knowledge and skill

Basic to live working is knowledge of the hazards and means of personal protection, by minimum approach distances and other methods. Workers need to be thoroughly trained in live work and in the job at hand. During work, attention needs to be shared between the work being performed and respecting the minimum approach distance. Adequate training and practice in the work procedure will reduce the possibility of attention being diverted from respecting the minimum approach distance by unexpected situations.

A.3 Protective barriers

A barrier is an obstacle that is in place to reduce or eliminate the ergonomic distance requirement. It limits the distance workers can reach or approach to anything that is at a different electric potential. A barrier could be metallic or non-metallic material.

A.4 Possibility of error

The possibility of errors being committed during the work depends on the work procedure being used, personal factors, effects of the environment and the extent to which the workers actions are monitored by others.

A.5 Work procedure

Different work positions and methods will require different allowances for unintentional movement. The stability of the worker's position can also vary from task to task, e.g. working above the earth, compared with working on the earth. A complex or strenuous job is also more likely to divert the worker's attention away from observing the minimum approach distance.

Because of these factors, consideration could be given to using a different ergonomic distance for different work situations or procedures.

A.6 Personal factors

A worker's physical, mental and emotional states are also possible causes for unintentional movement. These factors are, in turn, influenced by the duration and strenuousness of the job, for instance. Live working requires constant attention, both to the procedures and the minimum approach distance, attention which can be readily distracted by personal factors. For this reason, self control and safety awareness are essential skills to work at the minimum approach distance.

A worker's ability to judge the minimum approach distance correctly is also important. For this reason it may be beneficial to increase the ergonomic distance with the voltage. However, too large a distance at high voltages will make small components on the live conductors difficult to see, and tools heavier to handle.

Workers should not wear clothing with loose parts that could fall, blow or swing close to the live conductors. This includes equipotential bonding leads of conductive suits.

A.7 Environmental factors

Certain environmental conditions are generally taken into account by prohibiting work at the minimum approach distance under those conditions. For instance, work is normally not permitted during nearby thunderstorms, or when there is a continuous film of water on the surface of insulating tools.

Adverse conditions may also be created by other environmental conditions, either directly, or by diverting attention away from the authorized work procedures. Strong winds move conductors, supports or equipment (e.g. aerial devices) dangerously. Dust storms are an eye hazard. Ice on structures will make footing insecure. Woodpecker holes present a climbing hazard. Mist or sea spray may pose a hazard to system or tool insulation. Smooth surfaces may be slippery. Darkness or glare may impair vision. Consideration should also be given to the effect of high temperature and humidity to worker fatigue. These are some of the environmental influences on work close to live conductors, some of which will need to be taken into account when establishing minimum approach distances.

A.8 Monitoring

To warn workers of dangerous situations arising during the work, it can be sometimes beneficial to require continuous monitoring by an observer. Failing that, the workers should be encouraged to describe aloud to one another each step in the work procedure before taking it. The procedure to be followed should also be detailed and discussed between the foreman and workers before commencing work.

Annex B (informative)

Overvoltages

B.1 The different types of overvoltages

The overvoltage values are expressed in p.u., and 1 p.u. is equal to $U_s \sqrt{2} / \sqrt{3}$ (see 2.1.10).

According to IEC 60071-1, voltages and overvoltages are divided in the classes shown in Table B.1.

Table B.1 – Classification of overvoltages according to IEC 60071-1

Class	Low frequency		Transient		
	Continuous	Temporary	Slow-front	Fast-front	Very-fast-front
Voltage or over-voltage shapes					
Range of voltage or over-voltage shapes	$f = 50 \text{ Hz or } 60 \text{ Hz}$ $T_t \geq 3 \text{ 600 s}$	$10 \text{ Hz} < f < 500 \text{ Hz}$ $0,02 \text{ s} \leq T_t \leq 3 \text{ 600 s}$	$20 \text{ }\mu\text{s} < T_p \leq 5 \text{ 000 }\mu\text{s}$ $T_2 \leq 20 \text{ ms}$	$0,1 \text{ }\mu\text{s} < T_1 \leq 20 \text{ }\mu\text{s}$ $T_2 \leq 300 \text{ }\mu\text{s}$	$T_f \leq 100 \text{ ns}$ $0,3 \text{ MHz} < f_1 < 100 \text{ MHz}$ $30 \text{ kHz} < f_2 < 300 \text{ kHz}$
Standard voltage shapes	 $f = 50 \text{ Hz or } 60 \text{ Hz}$ T_t^a	 $48 \text{ Hz} \leq f \leq 62 \text{ Hz}$ $T_t = 60 \text{ s}$	 $T_p = 250 \text{ }\mu\text{s}$ $T_2 = 2 \text{ 500 }\mu\text{s}$	 $T_1 = 1,2 \text{ }\mu\text{s}$ $T_2 = 50 \text{ }\mu\text{s}$	a
Standard withstand voltage test	a	Short-duration power frequency test	Switching impulse test	Lightning impulse test	a
^a To be specified by the relevant apparatus committees.					

For live working applications, the overvoltages of major concern, in the voltage range of interest, are the slow front overvoltages due to switching operations. Fast front transients, such as lightning overvoltages, are not generally of importance, since live work is not normally performed under conditions of inclement weather. Lightning may cause flashover at the strike location. Otherwise the resulting overvoltage is attenuated such that the impulse level will not result in a flashover at the work location, that is, at distances over 10 km. Permanent and temporary low frequency overvoltages are usually also not of concern, since they are not critical for the air gaps which are required to withstand switching overvoltages during live work.

In unusual circumstances, significant low frequency overvoltages may arise due to ferro-resonance of network elements in unstable configurations. This hazard should be addressed by procedures which ensure that the phenomenon is avoided.

B.2 Transient slow-front overvoltages

Slow-front overvoltage amplitudes depend on many parameters such as the characteristics of the system, the point of the system, the type of event considered. Moreover, even at the same point and for the same family of events, the overvoltages have a statistical nature. So slow-front overvoltage amplitudes are evaluated on the basis of a statistical approach: reference is usually made to the overvoltage having the probability of 2 % to be reached or exceeded (U_{e2} for phase to earth and U_{p2} for phase to phase) and to the standard deviation of the statistical distribution, assumed as gaussian, σ .

The most common overvoltage families are examined in the following.

B.2.1 Origin and typical values

B.2.1.1 Phase to earth overvoltages

Closing and reclosing overvoltages are among the most frequent type of overvoltages.

The amplitudes of the phase to earth overvoltages depend on many parameters: feeding network (short circuit power, zero to positive sequence impedance ratio, configuration, actual voltage level on the feeding), switched line (length, electrical characteristics, level of residual voltage left by previous energization), line shunt compensation, energized parallel lines, circuit breakers (pole span, prestrike, phase angle at the instant of switching, closing resistors), point along the switched line (the voltage distribution along the line is rising from the substation to the opposite end).

Figure B.1 summarizes the maximum amplitude ranges of phase to earth overvoltages at line energization depending on the various conditions considered. The range of u_{e2} is quite large ranging from about 1,2 to about 2,8 for closing operations and from about 1,5 to about 3,8 for reclosing operations.

Other means to reduce overvoltages, not considered in Figure B.1, are surge arresters, co-ordinating gaps or synchronized switching.