



Part 3: Mutual Interaction of a.c. and d.c. traction systems

National foreword

This British Standard is the UK implementation of EN 50122-3:2010.

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**Railway applications -
Fixed installations -
Electrical safety, earthing and the return circuit -
Part 3: Mutual Interaction of a.c. and d.c. traction systems**

Applications ferroviaires -
Installations fixes -
Sécurité électrique, mise à la terre et
circuit de retour -
Partie 3: Interactions mutuelles entre
systèmes de traction en courant alternatif
et en courant continu

Bahnanwendungen -
Ortsfeste Anlagen -
Elektrische Sicherheit, Erdung und
Rückleitung -
Teil 3: Gegenseitige Beeinflussung von
Wechselstrom- und
Gleichstrombahnsystemen

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Foreword

This European Standard was prepared by SC 9XC, Electric supply and earthing systems for public transport equipment and ancillary apparatus (Fixed installations), of Technical Committee CENELEC TC 9X, Electrical and electronic applications for railways. It was submitted to the formal vote and was approved by CENELEC as EN 50122-3 on 2010-10-01.

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The following dates were fixed:

- latest date by which the EN has to be implemented
at national level by publication of an identical
national standard or by endorsement (dop) 2011-10-01
- latest date by which the national standards conflicting
with the EN have to be withdrawn (dow) 2013-10-01

This draft European Standard has been prepared under a mandate given to CENELEC by the European Commission and the European Free Trade Association and covers essential requirements of EC Directives 96/48/EC (HSR), 2001/16/EC (CONRAIL) and 2008/57/EC (RAIL). See Annex ZZ.

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1 Scope

This European Standard specifies requirements for the protective provisions relating to electrical safety in fixed installations, when it is reasonably likely that hazardous voltages or currents will arise for people or equipment, as a result of the mutual interaction of a.c. and d.c. electric traction systems.

It also applies to all aspects of fixed installations that are necessary to ensure electrical safety during maintenance work within electric traction systems.

The mutual interaction can be of any of the following kinds:

- parallel running of a.c. and d.c. electric traction systems;
- crossing of a.c. and d.c. electric traction systems;
- shared use of tracks, buildings or other structures;
- system separation sections between a.c. and d.c. electric traction systems.

Scope is limited to basic frequency voltages and currents and their superposition. This European Standard does not cover radiated interferences.

This European Standard applies to all new lines, extensions and to all major revisions to existing lines for the following electric traction systems:

- a) railways;
- b) guided mass transport systems such as:
 - 1) tramways,
 - 2) elevated and underground railways,
 - 3) mountain railways,
 - 4) trolleybus systems, and
 - 5) magnetically levitated systems, which use a contact line system;
- c) material transportation systems.

The standard does not apply to:

- d) mine traction systems in underground mines;
- e) cranes, transportable platforms and similar transportation equipment on rails, temporary structures (e.g. exhibition structures) in so far as these are not supplied directly or via transformers from the contact line system and are not endangered by the traction power supply system for railways;
- f) suspended cable cars;
- g) funicular railways;
- h) procedures or rules for maintenance.

NOTE The rules given in this European Standard can also be applied to mutual interaction with non-electrified tracks, if hazardous voltages or currents can arise from a.c. or d.c. electric traction systems.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 50122-1:2010, *Railway applications – Fixed installations – Electrical safety, earthing and the return circuit – Part 1: Protective provisions against electric shock*

EN 50122-2:2010, *Railway applications – Fixed installations – Electrical safety, earthing and the return circuit – Part 2: Provisions against the effects of stray currents caused by d.c. traction systems*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 50122-1:2010 apply.

4 Hazards and adverse effects

4.1 General

The different requirements specified in EN 50122-1 and EN 50122-2, concerning connections to the return circuit of the a.c. railway, and connections to the return circuit of the d.c. railway, shall be harmonized in order to avoid risks of hazardous voltages and stray currents.

Such hazards and risks shall be considered from the start of the planning of any installation which includes both a.c. and d.c. railways. Suitable measures shall be specified for limiting the voltages to the levels given in this European Standard, while limiting the damaging effects of stray currents in accordance with EN 50122-2.

NOTE Additional adverse effects are possible, for example:

- thermal overload of conductors, screens and sheaths;
- thermal overload of transformers due to magnetic saturation of the cores;
- restriction of operation because of possible effects on the safety and correct functioning of signalling systems;
- restriction of operation because of malfunction of the communication system.

These effects should be considered in accordance with the appropriate standards.

4.2 Electrical safety of persons

Where a.c. and d.c. voltages are present together the limits for touch voltage given in Clause 7 apply in addition to the limits given in EN 50122-1:2010, Clause 9.

5 Types of mutual interaction to be considered

5.1 General

Coupling describes the physical process of transmission of energy from a source to a susceptible device.

The following types of coupling shall be considered:

- a) galvanic (conductive) coupling;
- b) non-galvanic coupling;
 - 1) inductive coupling;
 - 2) capacitive coupling.

Galvanic coupling dominates at low frequencies, when circuit impedances are low. The effects of galvanic coupling are conductive voltages and currents.

The effects of inductive coupling are induced voltages and hence currents. These voltages and currents depend *inter alia* on the distances, length, inducing current conductor arrangement and frequency.

The effects of capacitive coupling are influenced voltages into galvanically separated parts or conductors. The influenced voltages depend *inter alia* on the voltage of the influencing system and the distance. Currents resulting from capacitive coupling are also depending on the frequency.

NOTE As far as the capacitive and inductive coupling are concerned, general experience is that only the influence of the a.c. railway to the d.c. railway is significant.

5.2 Galvanic coupling

5.2.1 A.C. and d.c. return circuits not directly connected

A mutual interaction between the return circuits is possible by currents through earth caused by the rail potential of both a.c. and d.c. railways, for example return currents flowing through the return conductors, earthing installations of traction power supply substations and cable screens.

In case a conductive parallel path to the return circuit exists in the influenced system, various effects are possible. In case a vehicle forms part of the parallel path, return current of the influencing railway system can flow through the propulsion system of the traction unit. The same effects are possible when the return current of the influencing system flows, for example, through the auto-transformer and substation transformer of an auto-transformer system or through booster transformers or other devices.

An electric shock with combined voltages can occur when parts of the return circuits or conductive parts which are connected to the return circuits by voltage limiting devices are located in the overhead contact line zone of the other railway system, see 8.2.2.

5.2.2 A.C. and d.c. return circuits directly connected or common

In addition to the effects described in 5.2.1 current exchange will be increased where a.c. and d.c. return circuits are directly connected or common.

NOTE Direct connections can be railway level crossings, common tracks, system separation sections, etc.

Currents flowing between the a.c. railway and the d.c. railway can create mutual interaction between the return circuits.

Both return circuits are at the same potential at the location of the connection. A short-circuit within the a.c. system can cause a peak voltage on conductive structures connected to the return circuit of the d.c. railway. The same effects apply for conductive structures connected to it directly or via a voltage limiting device (VLD). The voltage across the voltage limiting device can trip the device without a fault on the d.c. side.

The connection of the return circuit of the d.c. railway to the earthed return circuit of the a.c. railway increases the danger of stray current corrosion.

For requirements for fixed installations see 8.3.

5.3 Non-galvanic coupling

5.3.1 Inductive coupling

An a.c. voltage can be induced on a d.c. contact line system and on the d.c. system's return circuit. This effect needs to be considered in case the d.c. railway is within the zone of mutual interaction.

Consequently an a.c. voltage can occur within the d.c. substation at the busbars versus earth (i.e. at the rectifier or in the feeder cubicles).

Interaction can occur in terms of impermissible touch voltages. See Clause 7.

Perpendicular crossings do not result in inductive effects in the d.c. system.

5.3.2 Capacitive coupling

Within small distances an a.c. voltage can be influenced on a d.c. contact line system when it is isolated with a disconnector or circuit-breaker open. The possibility shall be considered that the flash-over voltage of the insulators or of the surge arrestors can be reached.

NOTE Distance depends *inter alia* on geometry and voltage.

An a.c. voltage can occur within the d.c. substation at the d.c. busbars versus earth, i.e. in the feeder cubicles.

Interaction can occur in terms of impermissible touch voltages. See Clause 7.

6 Zone of mutual interaction

6.1 General

The a.c. railway affects the d.c. railway and vice-versa by galvanic, inductive and/or capacitive coupling (see Clause 5). The zone of mutual interaction indicates a distance and a length of parallelism between an a.c. railway and a d.c. railway (see Annex A). The limits of zone of mutual interaction are based on the limits of the touch voltage given in Clause 7.

If a zone of mutual interaction exists the requirements given in this European Standard shall be fulfilled.

When the distance between both a.c. and d.c. railways is less than 50 m a zone of mutual interaction is assumed. Distances in excess of 50 m are dealt with in 6.2 and 6.3.

NOTE 1 When the distance between a.c. and d.c. railways becomes less than 50 m effects as described in 5.2.1 or even 5.2.2 can be expected.

NOTE 2 Distances between a.c. railway and the d.c. railway cannot be given in a generic way and should be addressed separately depending on the local conditions.

NOTE 3 For information on analysis and assessment of zone of mutual interaction see Annex C.

6.2 A.C.

In case of an a.c. railway influencing a d.c. railway the zone of mutual interaction is based on voltages coupled into the affected system.

Where the following preconditions apply the limit of the distance between a.c. and d.c. railway is 1 000 m:

- double track line, where only the four running rails of the a.c. railway are used for the return circuit;
- the inducing current is 500 A per overhead contact line (1 000 A in total);
- the length of parallelism between a.c. and d.c. railway is 4 km;
- the soil resistivity is 100 Ω m;
- the rated frequency is 50 Hz;
- the affected system is insulated versus earth along its entire length and connected to earth at one end only;
- screening effects of other parallel metallic objects have not been taken into account.

Where other preconditions apply the dimension of the zone of mutual interaction shall be calculated.

NOTE 1 A method for the calculation is given in Annex A.

NOTE 2 The example above is based on a 35 V limit for a.c. with a time duration longer than 300 s.

In case a d.c. railway is within the zone of mutual interaction of an a.c. railway, the level of voltages or currents coupled into the d.c. system is not necessarily too high; in this case further analysis of the situation shall be carried out.

6.3 D.C.

For the effects of d.c. railway systems on a.c. railway systems the dimension of the zone of mutual interaction can be neglected due to the steep voltage gradient in the soil, caused by the insulated rails.

However if the possibility of a voltage transfer exists, either permanently or temporary, due to a galvanic connection towards conductive or partly conductive parts, the zone of mutual interaction is given by the dimensions of those parts. In this case the level of voltages or currents coupled into the a.c. system is not necessarily too high; further analysis of the situation shall be carried out.

7 Touch voltage limits for the combination of alternating and direct voltages

7.1 General

The limits given in 7.2 to 7.6 are based on touch voltage only and shall not be exceeded. Other effects with respect to electrical installations are not taken into account.

NOTE 1 Limits for electrical installations cannot be given in a generic way and should be addressed separately if necessary, depending on the sensitivity of the affected installations.

Where either an alternating or a direct voltage is present the touch voltage limits given in EN 50122-1 apply.

The direct and the alternating components of a combined voltage $u(t)$ for time duration in excess of 1 s are calculated as follows:

$$U_{dc} = \frac{1}{T} \cdot \int_a^{a+T} u(t) \cdot dt \quad (1)$$

$$U_{ac} = \sqrt{\frac{1}{T} \cdot \int_a^{a+T} (u(t) - U_{dc})^2 \cdot dt} \quad (2)$$

where

T = 1 s;

t is the time;

$u(t)$ is the combined voltage;

U_{dc} is the direct component of combined voltage;

U_{ac} is the alternating component of combined voltage.

NOTE 2 Equation (1) gives the moving average value of the direct component, Equation (2) gives the moving r.m.s. value of the alternating component.

Only for short-duration phenomena $t \leq 1$ s the following definitions for alternating voltage and direct voltage are used:

- U_{dc} is defined as that part of the combined voltage that is caused by the d.c. system;
- U_{ac} is defined as that part of the combined voltage that is caused by the a.c. system.

NOTE 3 Further information on combined voltages is given in Annex B.

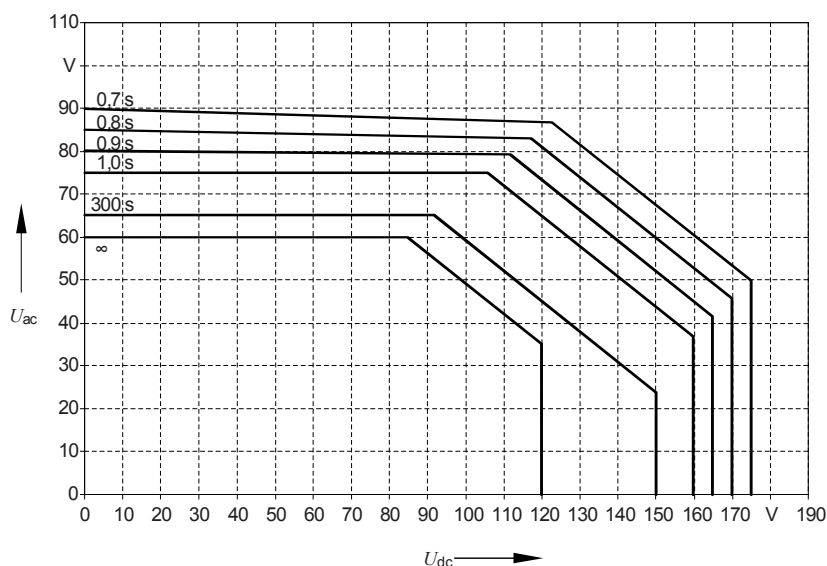
NOTE 4 Long-term conditions are associated with operation conditions and short-term conditions are associated with fault conditions or for example switching operations.

7.2 Touch voltage limits for long-term conditions

The following approach shall be used to check whether the combined voltage is permissible:

1. the alternating part of the combined voltage shall not exceed the maximum permissible alternating body voltage as given in EN 50122-1:2010, Table 3 for the applicable duration;
2. the direct part of the combined voltage shall not exceed the maximum permissible direct body voltage as given in EN 50122-1:2010, Table 5 for the applicable duration;
3. the combined voltage is permissible if it is within the envelope as given for the applicable duration in Figure 1;
4. for time durations in excess of 1 s the combined peak value (see explanation in Annex B) shall be less than $2 \times \sqrt{2}$ times the maximum permissible alternating body voltage as given in EN 50122-1:2010, Table 3 for the applicable duration irrespective of frequency content.

NOTE Assuming the maximum permissible direct touch voltage of 120 V being present in the d.c. system the alternating voltage limit is 35 V, see Figure 1. Assuming the maximum permissible alternating touch voltage of 60 V being present in the a.c. system the direct voltage limit is 85 V, see Figure 1.



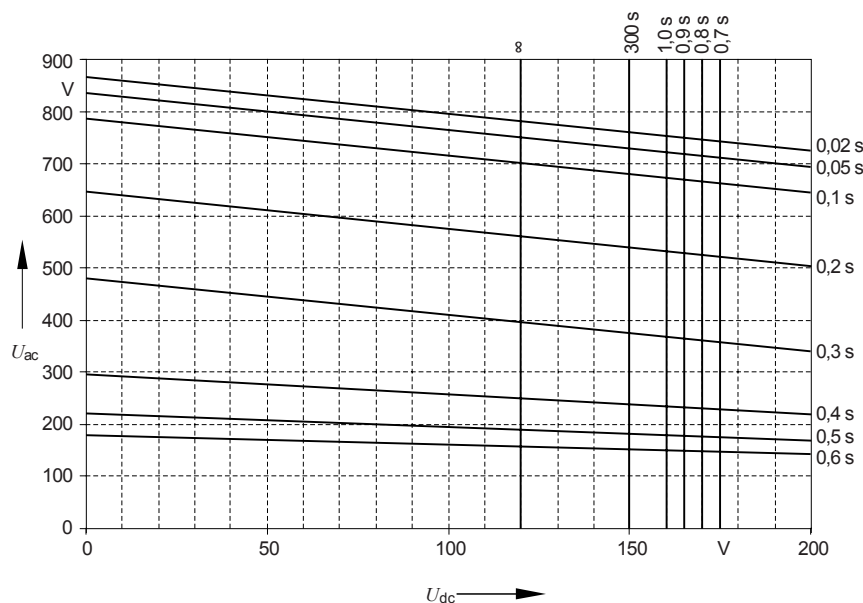
NOTE All values are r.m.s.

Figure 1 — Maximum permissible combined effective touch voltages (excluding workshops and similar locations) for long-term conditions

7.3 A.C. system short-term conditions and d.c. system long-term conditions

The following approach shall be used to check whether the combined voltage is permissible:

1. the short-duration alternating part of the combined voltage shall not exceed the maximum permissible alternating touch voltage as given in EN 50122-1:2010, Table 4 for the applicable duration;
2. the direct part of the combined voltage shall not exceed the maximum permissible direct touch voltage as given in EN 50122-1:2010, Table 6 for the applicable duration;
3. the combined voltage is permissible if it is within the envelope as given for the applicable durations in Figure 2.



NOTE All values are r.m.s.

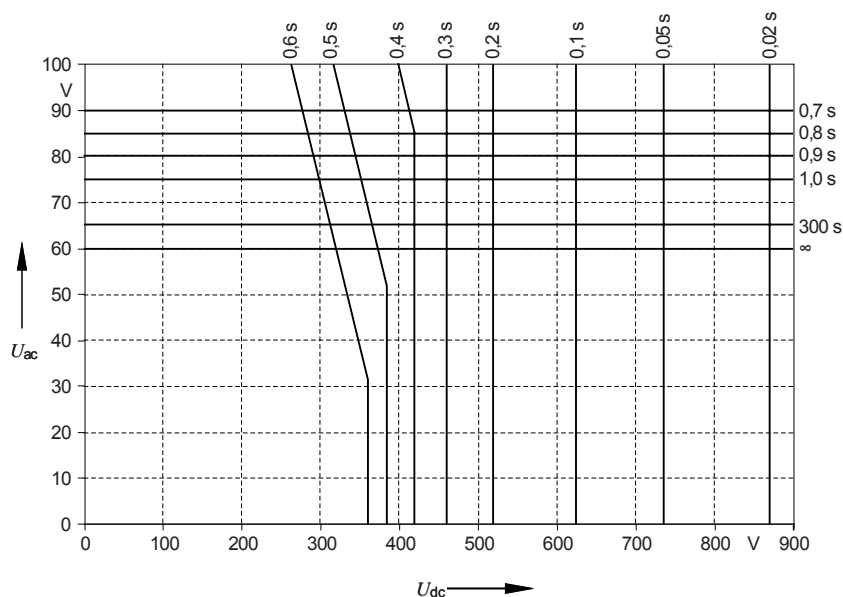
Figure 2 — Maximum permissible combined effective touch voltages under a.c. short-term conditions and d.c. long-term conditions

NOTE An example of the use of Figure 2 is given in Annex B.

7.4 A.C. system long-term conditions and d.c. system short-term conditions

The following approach shall be used to check whether the combined voltage is permissible:

1. the alternating part of the combined voltage shall not exceed the maximum permissible alternating touch voltage as given in EN 50122-1:2010, Table 4 for the applicable duration;
2. the short-duration direct part of the combined voltage shall not exceed the maximum permissible direct touch voltage as given in EN 50122-1:2010, Table 6 for the applicable duration;
3. the combined voltage is permissible if it is within the envelope as given for the applicable durations in Figure 3.



NOTE All values are r.m.s.

Figure 3 — Maximum permissible combined effective touch voltages under a.c. long-term conditions and d.c. short-term conditions

7.5 A.C. system short-term conditions and d.c. system short-term conditions

Simultaneous short-term phenomena in the a.c. system and in the d.c. system do not need to be considered.

NOTE It is unlikely that short-term phenomena occur at the same time in both the a.c. system and the d.c. system, and that the return circuit is touched at the same moment.

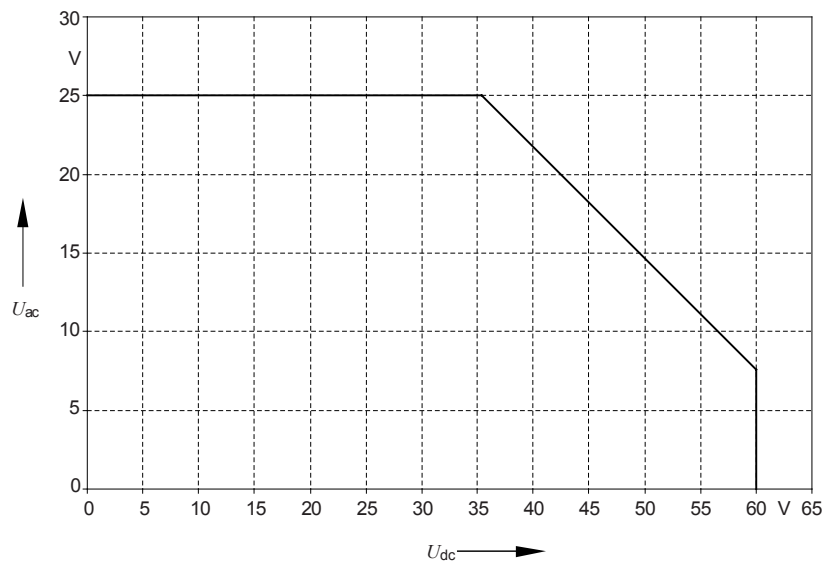
7.6 Workshops and similar locations

For long-term conditions the following approach shall be used to check whether the combined voltage is permissible:

1. the alternating part of the combined voltage shall comply with EN 50122-1:2010, 9.2.2.3;
2. the direct part of the combined voltage shall comply with EN 50122-1:2010, 9.3.2.3;
3. the combined voltage is permissible if it is within the envelope as defined in Figure 4.

For short-term conditions 7.3, 7.4 and 7.5 apply.

NOTE Assuming the maximum permissible direct touch voltage of 60 V being present in the d.c. system the alternating voltage limit is 8 V. Assuming the maximum permissible alternating touch voltage of 25 V being present in the a.c. system the direct voltage limit is 35 V, see Figure 4.



NOTE All values are r.m.s.

Figure 4 — Maximum permissible combined effective touch voltages in workshops and similar locations excluding short-term conditions

8 Technical requirements and measures inside the zone of mutual interaction

8.1 General

All installations shall comply with the requirements of EN 50122-1 and EN 50122-2. Additional provisions are described hereunder.

8.2 Requirements if the a.c. railway and the d.c. railway have separate return circuits

8.2.1 General

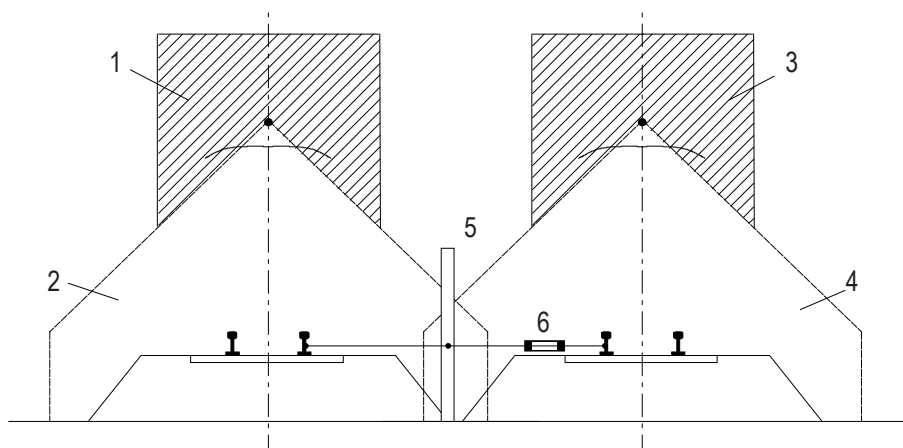
This clause applies if there is no return circuit connection between the a.c. railway and the d.c. railway.

8.2.2 Return circuit or parts connected to the return circuit located in the OCLZ and/or CCZ of the other system

An assessment shall be made of whether the application of EN 50122-1:2010, Clause 6 will require conductive connections to be made between the return circuit of the a.c. railway and the return circuit of the d.c. railway. If such connections are required, then the voltage-limiting devices which are required by EN 50122-1:2010, 6.2.2 shall be specified to detect and operate with alternating voltages and currents in addition to direct voltages and currents, so that compliance is achieved with Clause 7 of this European Standard. See EN 50122-1:2010, Annex F.

If the return circuit, parts connected to the return circuit or the vehicles of the a.c. railway are within the overhead contact line zone or the current collector zone of the d.c. railway, or vice versa, then voltage-limiting devices (minimum function VLD-F) shall be connected between the return circuit of the d.c. railway and the return circuit of the a.c. railway.

EXAMPLE See Figure 5.



Key

- 1 current collector zone of a.c. line
- 2 overhead contact line zone of a.c. line
- 3 current collector zone of d.c. line
- 4 overhead contact line zone of d.c. line
- 5 fence or other conductive part (bonded to the return circuit of the a.c. line)
- 6 voltage limiting device

Figure 5 — Example of where a VLD shall be suitable for both alternating and direct voltage

The design of the systems shall be such that the voltage-limiting devices will not conduct during operating conditions in order to meet the requirements of EN 50122-2.

The risks associated with the conductive state of voltage-limiting devices shall be assessed.

8.2.3 Common buildings and common structures

8.2.3.1 Selection of the strategy for earthing

An assessment shall be made, at an early planning stage, whether it is desirable and possible to separate the part of the structure earth associated with the a.c. railway from the part of the structure earth associated with the d.c. railway, and to separate either part of the structure earth from earthing systems outside the common building or structure. In all cases the paths taken by earth fault current from the a.c. contact line and the d.c. contact line shall be identified, and conductors of sufficient cross-sectional area shall be provided. See EN 50122-1:2010, Clause 7 for non-traction power supplies.

8.2.3.2 Separation of structure earths

If the structure earths are separated, then insulating gaps or joints are required.

To prevent bypassing of the insulating gaps, PE conductors of electricity supply cables, the screens of communications cables, metal pipes and similar items which pass from one part of the building to another, or enter the building from outside require an insulating joint. The insulating gaps and relating equipment shall be installed at the borders of the separated structure earths. The relevant systems shall be designed so that they will function safely when the insulating gaps are in place.

Where it is necessary to include insulating gaps in underground parts of the building, the insulating sections shall be of sufficient length that significant current will not flow past them by conduction through the soil.

NOTE 1 It has been found that a distance of 1 m is sufficient if the resistivity of the soil is greater than 500 Ωm ; otherwise a distance of 2 m is required.

NOTE 2 Provision should be made to detect unintended connections between the two structure earths.

8.2.3.3 Common structure earth

If the structure earths are connected, then attention shall be paid to the risk of stray currents in the a.c. railway and in the earthing systems outside the railway structures. See EN 50122-2:2010, Clause 7.

NOTE Provision should be made to detect the possible danger caused by stray currents in the a.c. railway, the structure earth and the outside earths. See EN 50122-2:2010, Clause 10.

8.2.4 Inductive and capacitive coupling

The voltages induced or influenced by the a.c. railway into the contact lines and cables of the d.c. railway, and the voltages induced into the rails and cables beside the d.c. railway, shall be evaluated and corrective measures shall be applied as needed.

NOTE The rails of the d.c. railway can pick up significant induced voltages if they are well insulated from the earth according EN 50122-2. Communication circuits beside the d.c. railway can need the same kind of measures as are needed by the communication circuits beside the a.c. railway.

Precautions shall be taken against excessive a.c. voltages on the d.c. contact lines when they are disconnected from the substations and are not earthed.

When assessing compliance, the indivisible sub-section of the d.c. contact line which is most closely coupled with the a.c. railway shall be considered. The voltages coupled in into the d.c. system shall be taken into the consideration in the design of the d.c. system.

8.3 Requirements if the a.c. railway and the d.c. railway have common return circuits and use the same tracks

8.3.1 General

This clause applies to a.c. and d.c. electric traction systems on the same tracks as well as to level crossings between an a.c. railway and a d.c. railway.

8.3.2 Measures against stray current

Measures shall be applied to prevent the flow of significantly damaging levels of stray current between the tracks electrified only with a.c. and the tracks electrified only with d.c. The running rails of the tracks equipped with both systems shall be insulated from the earth in accordance with EN 50122-2:2010, 6.4. The connections which are required by EN 50122-1:2010, 6.2, shall be made using voltage-limiting devices (VLD) which can conduct both a.c. and d.c. The voltage-limiting devices shall be applied in accordance with EN 50122-1:2010, Annex F.

NOTE 1 Examples in accordance with EN 50122-1:2010, 6.2 are the connections via VLD from the running rails to the contact line supports and the structure earth, which are required by the presence of high-voltage contact lines.

The design of the railway traction power supply systems shall be such that the voltage-limiting devices will not conduct except during extraordinary operating conditions in order to meet the requirements of EN 50122-2.

The risks associated with the conductive state of voltage-limiting devices shall be assessed.

NOTE 2 The above measures cause a lack of earthing of the tracks. Therefore special measures can be necessary in order to achieve sufficiently low alternating voltages on the running rails. Such measures can include the use of isolating transformers, booster transformers and return conductors insulated from earth.

NOTE 3 Experience shows that a practical design can be produced if the alternating voltage and the direct voltage on the rail are each significantly less than 25 V as r.m.s. value for 1 min, and significantly below 10 V as r.m.s. value over 30 min.

8.3.3 Common structures and common buildings

The requirements of 8.2.3 apply equally where a.c. and d.c. electric traction systems are provided on the same tracks, except that the separation of the structure earth into an a.c. part and a d.c. part is not relevant.

Particular attention shall be given to the risks of stray current in structures, electrical earthing systems, pipes and similar items outside the common building.

8.3.4 Exceptions

The requirements of 8.3.2 and 8.3.3 can be reduced if it is shown that significant damage by stray current will not occur if the running rails of the d.c. system are earthed as for the a.c. system.

NOTE Such exception can be possible if at least one of the following preconditions apply:

- the d.c. traction system uses an insulated return conductor rail (for example the “fourth rail”) for the traction return current;
- the d.c. system has a low voltage drop along the running rails for example due to low traction current or short length of feeding sections, see also EN 50122-2; a possible measure is also to provide insulated return conductors in parallel with the running rails;
- the tracks equipped with both systems are separated electrically from the remainder of the d.c. system by means of insulating rail joints and related equipment;
- duration of use of buildings is shorter than the period until the occurrence of expected damages, this includes structures owned by third parties.

8.3.5 Design of overhead contact line

The probability that a live a.c. conductor would fall onto a live d.c. conductor or vice-versa shall be minimised by design.

NOTE This includes the avoidance of flash-over of insulators or between both systems.

8.3.6 Inductive and capacitive coupling

Where a.c. and d.c. electric traction systems are installed on the same tracks 8.2.4 applies equally.

8.4 System separation sections and system separation stations

The transfer of stray currents shall be limited in accordance with EN 50122-2. The touch voltages shall comply with Clause 7.

The basic requirements are:

- to ensure the continuity of the return circuit for both alternating current and direct current, in all operating and fault conditions,
- to prevent electrical connections between the a.c. contact lines and the d.c. contact lines,
- to limit the current between the a.c. return circuit and the d.c. return circuit.

NOTE 1 A suitable way to limit the exchange of return current between the two systems is to use insulating rail joints in conjunction with special feeding and switching arrangements.

If insulating rail joints are used, the voltage across them shall be limited in order to avoid impermissible touch voltages.

NOTE 2 The voltages across insulating rail joints will be bridged by the vehicles.

System separation stations shall be treated as specified in 8.3.

Annex A (informative)

Zone of mutual interaction

A.1 Introduction

This annex gives information on how to determine the dimensions of the zone of mutual interaction. The purpose is not to calculate accurately the voltage coupled into the d.c. system due to an adjacent a.c. system.

A.2 A.C. system as source

A.2.1 Main parameters

The zone of mutual interaction from a.c. to d.c. is based on permissible voltages coupled into the affected d.c. railway system.

For the width of the zone of mutual interaction the following main parameters are of importance:

- a) type of traction power supply system used, either:
 - 1) standard system where only the running rails are used for traction return current,
 - 2) booster transformer system,
 - 3) auto transformer system;
- b) additional return conductors;
- c) inducing traction current;
- d) length of parallelism;
- e) geometry and distance between railways in case when railways are not exactly parallel;
- f) soil resistivity;
- g) fundamental frequency (e.g. 16,7 Hz or 50 Hz);
- h) screening by other metallic structures or effects of conductance to earth of the running rails, etc.

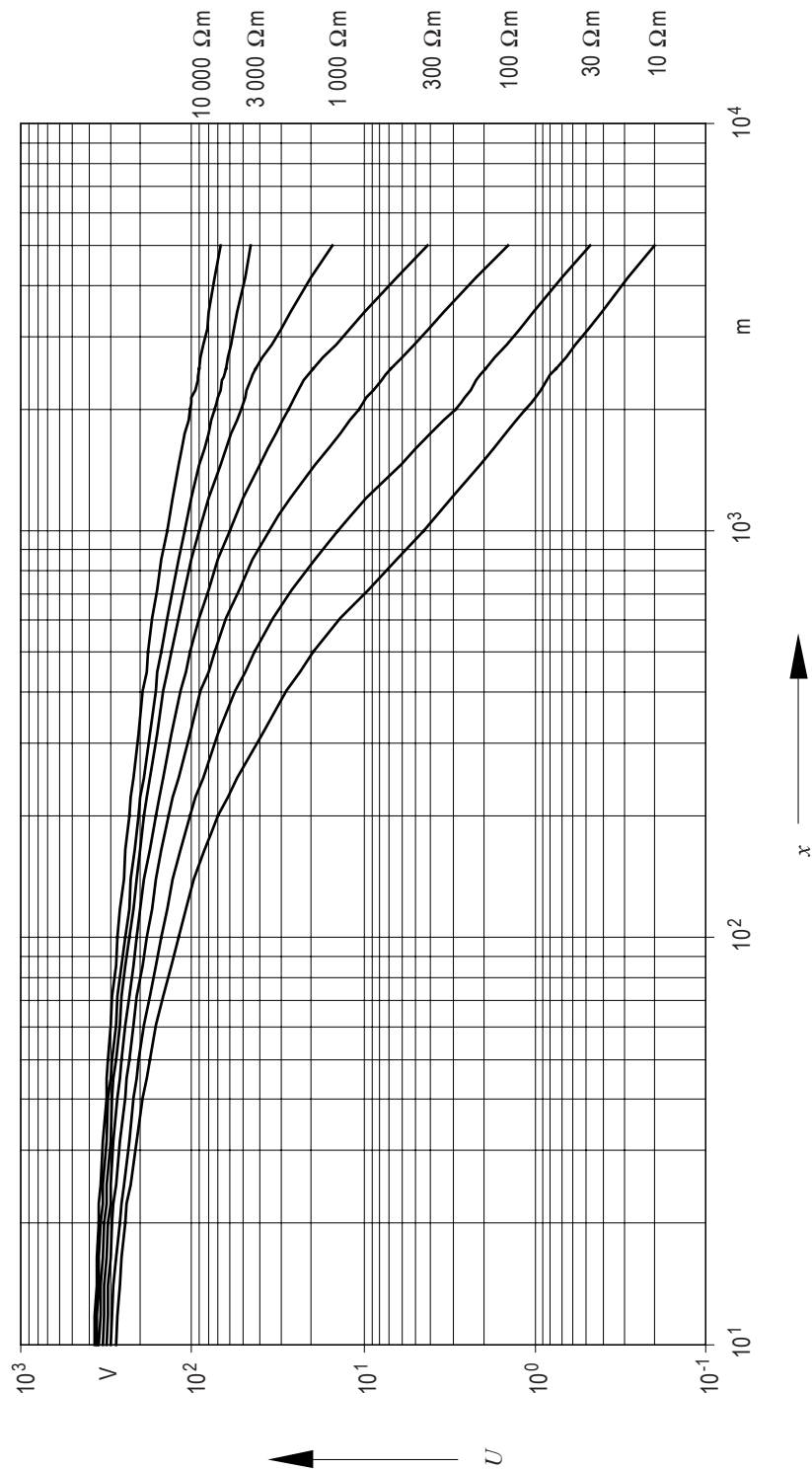
A.2.2 Basic analysis

For the basic evaluation the following basic parameters are used:

- double track line, where only the four running rails are used for the return circuit;
- the inducing current is 500 A per overhead contact line (1 000 A in total);
- the length of parallelism is assumed to be 4 km;
- the soil resistivity is variable between 10 Ωm and 10 000 Ωm ;
- the fundamental frequency is 50 Hz.

The induced voltage in a system, insulated versus earth and connected to earth at one end only, has been calculated for various soil resistivities and distances, see Figure A.1 (double logarithmic scale) and Figure A.2 (similar to Figure A.1, but linear scales). For the parameters given above and a soil resistivity of 100 Ωm the zone of mutual interaction is 1 000 m.

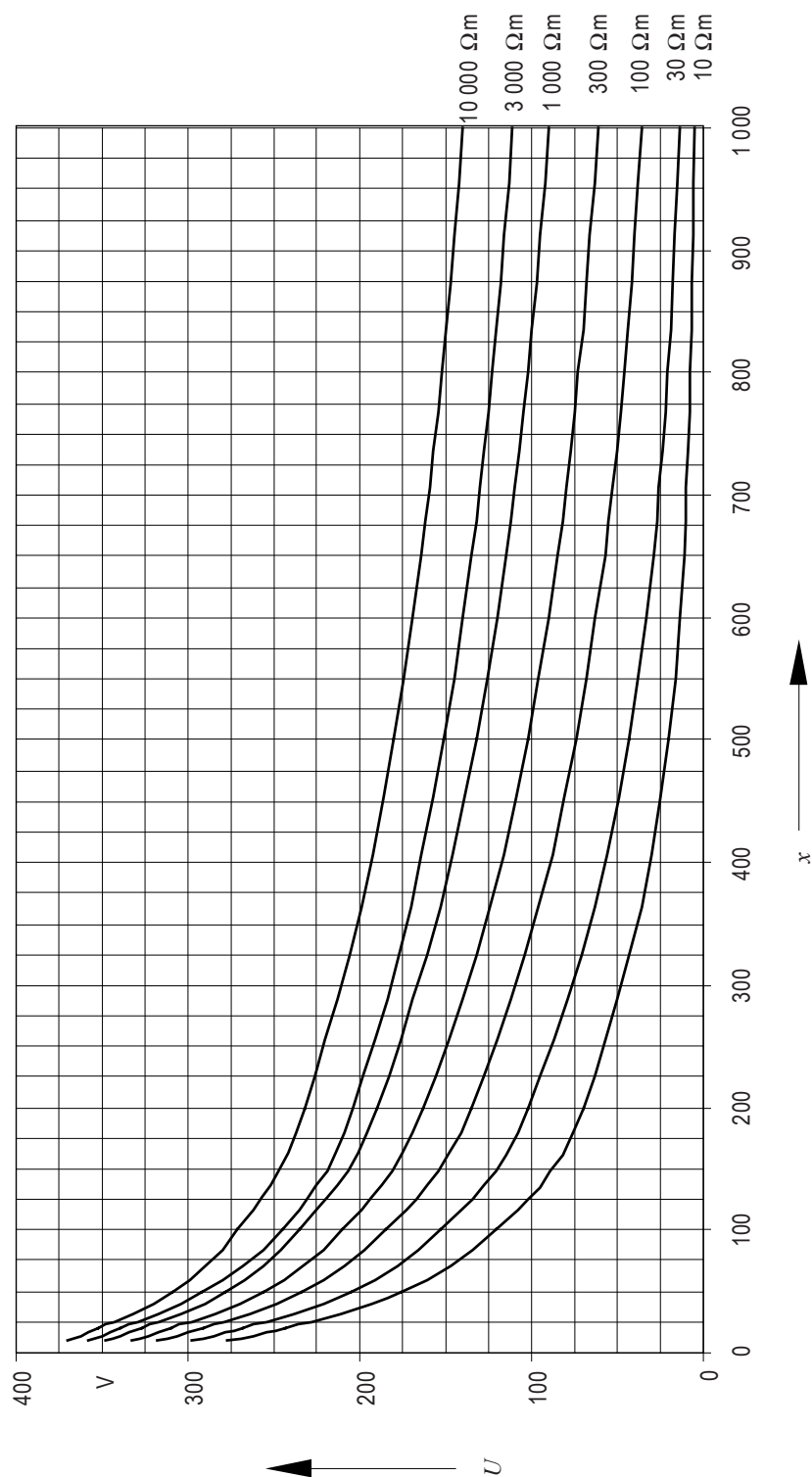
An example of the relation between the length of parallelism and the zone of mutual interaction can be found in Figure A.3.



Key

x distance between centre of tracks of a.c. and d.c. railway systems

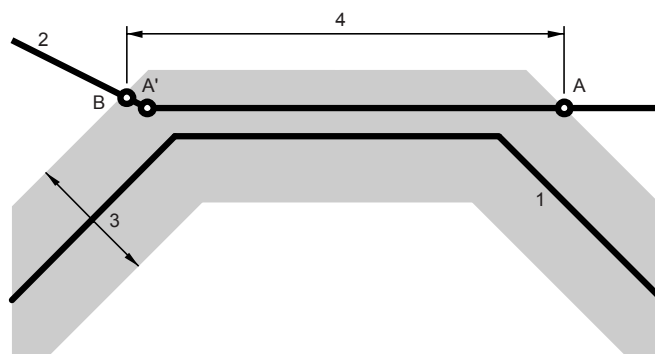
Figure A.1 — Overview of voltages coupled in as function of distance and soil resistivity I



Key

x distance, in metres, between centre of tracks of a.c. and d.c. railway systems

Figure A.2 — Overview of voltages coupled in as function of distance and soil resistivity II



Key

- 1 a.c. railway
- 2 d.c. railway
- 3 zone of mutual interaction caused by a.c. railway
- 4 length of parallelism

Figure A.3 — Relation between length of parallelism and zone of mutual interaction caused by an a.c. railway

A.2.3 Parameter variations

In case the parameters of the system under study differ from the values used for the derivation of the zone of mutual interaction in 6.2, the voltage coupled in the d.c. system can be approximated, using Figure A.1 and Figure A.2.

The voltage coupled into the d.c. system is linear with respect to:

- the inducing traction current,
- the length of parallelism.

The voltage coupled into the d.c. system is by approximation linear with respect to:

- the fundamental frequency (e.g. 16,7 Hz or 50 Hz).

The voltage coupled into the d.c. system depends also on:

- the distance between both electric traction systems,
- the type of the a.c. traction system,
- the presence of return conductors,
- the screening by other metallic structures or effects of conductance to earth of the running rails, etc., the so-called civilisation factor.

NOTE 1 It has been found by experience that the induced voltages in densely populated areas are lower than predicted by the basic theory, because of additional screening provided by earthed conductive structures, buried water pipes and similar items, parallel to the railway system. Also the conductance towards earth of the object under consideration has a mitigating effect.

NOTE 2 Generic specific factors for the comparison of different electric traction systems for example with or without auto-transformers and/or booster transformers cannot be given as the voltage coupled in depends on load position, positions of substations, auto-transformers and/or booster transformers.

NOTE 3 The approach used in this annex is based on an affected system which is insulated versus earth along its entire length and connected to earth at one end only. In case of not complete insulation, e.g. d.c. running rails, the conductance to earth of the running rails may be taken into account, also see the civilization factor.

The above leads to the following correction factors:

- a) current correction factor: $C_I = I_{trc}$ in kA divided by 1 kA;
- b) length of parallelism correction factor: $C_L = L_{//}$ in km divided by 4 km;
- c) frequency correction factor: $C_f = 0,3$ for 16,7 Hz,
 $C_f = 1,0$ for 50 Hz;
- d) system correction factor:
 - 1) standard system correction factor: $C_S = 1,0$;
 - 2) return conductor presence correction factor: $C_S = 0,4 \dots 0,7$ are typical values;
 - 3) auto-transformer or booster transformer system correction factor: $C_S = 0,1 \dots 0,4$ are typical values;
- e) civilisation factor: $C_C = 0,1 \dots 0,5$ are typical values.

Using the applicable correction factors, soil resistivity and distance for the graphs in Figure A.1 and Figure A.2 the voltage coupled into the d.c. system can be approximated using Equation (A.1):

$$U_{coupled} = C_I \times C_L \times C_f \times C_S \times C_C \times U_{graph}(\rho, d) \quad (A.1)$$

where

$U_{graph}(\rho, d)$ is the 50 Hz voltage for the applicable soil resistivity at the given distance.

Using Equation (A.1) and the graphs in Figure A.1 and Figure A.2 the zone of mutual interaction for other systems can be approximated.

NOTE 4 I_{trc} is the current in the considered contact line system section averaged along the length of parallelism.

NOTE 5 The value of the system correction factor for return conductor presence decreases with increasing frequency.

EXAMPLE 1 Task: Calculate the distance between the tracks of an a.c. railway and a d.c. railway for the zone of mutual interaction in case of a system with return conductors, a length of parallelism of 3,0 km, an average traction current of 0,5 kA with a frequency of 50 Hz and a soil resistivity of 300 Ω m. For the reference a.c. system of 6.2 with a soil resistivity of 300 Ω m a distance of 1 700 m is needed to obtain a value of 35 V, as given by Figure A.1. However in this case the voltage has to be corrected by a factor of $0,5 \times 0,75 \times 1 \times 0,45 \times 1 = 0,17$. Using the graph in Figure A.2 for 300 Ω m and the value of 210 V ($\approx 35 \text{ V} / 0,17$) a distance of 100 m is found.

EXAMPLE 2 Task: Calculate the maximum length of parallelism for the tracks of an a.c. railway and a d.c. railway of the zone of mutual interaction in case of a standard system with a distance of 10 m between a.c. railway and d.c. railway, an average traction current of 2,0 kA with a frequency of 16,7 Hz and a soil resistivity of 1 000 Ω m in an urban environment for a voltage coupled in of 35 V. A civilisation factor of 0,3 is assumed. The result is a correction factor of $2 \times 0,334 \times 1 \times 0,3 = 0,2$. Using the graph in Figure A.2 for a distance of 10 m and for a soil resistivity of 1 000 Ω m a value of 350 V is found. Using the correction factor 0,2 the result is a value of 70 V for 4 000 m length of parallelism. This gives a length of 2 000 m to obtain 35 V.

A.3 D.C. system as source

In general the influence of a d.c. railway system on an a.c. system with respect to voltages coupled in the a.c. system is small. Due to the insulation of the return circuit from the soil, the voltage gradient close to the rail is steep, mainly across the insulation of the rail fastenings. More far away in the soil it is small. Hence, in comparison to a.c. systems the zone of mutual interaction is considerably smaller.

If due to galvanic coupling, either by conductive or partly conductive parts a voltage transfer is possible, either permanent or temporary, the dimension of zone of mutual interaction is identical with dimension of conductive or partially conductive parts.

When the distance of the return circuits of both a.c. railway and d.c. railway becomes less than 50 m the same effects as described in 5.2.2 are expected.

Annex B (informative)

Analysis of combined voltages

EN 50122-1 deals with the impact on human beings of a.c. and d.c. systems separately, taking into account fundamental frequencies only. In this annex the effects of combined voltages are analysed.

Where an a.c. voltage and a d.c. voltage are present together, a method based on the following principle can be employed to decide whether the combined effect of the a.c. voltage and the d.c. voltage is permissible or not.

The important property of the wave-form is the combined peak value which for this purpose is defined as the largest of:

1. the positive peak value relative to 0 V,
2. the absolute value of the negative peak value relative to 0 V,
3. the peak-to-peak value.

These quantities are explained in Figure B.1.

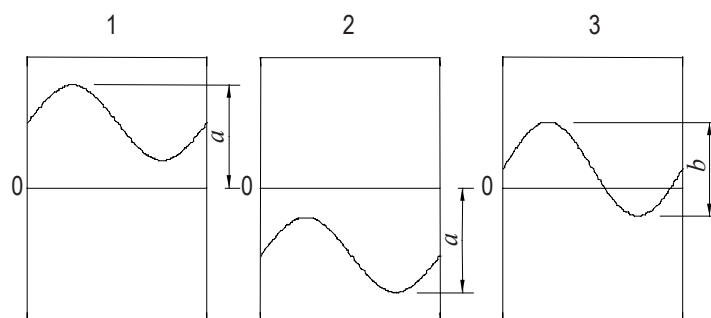
As stated in Clause 7, for a duration $t > 1,0$ s the voltage is permissible if the combined peak value of the wave-form is less than the permissible r.m.s. value of the alternating voltage according to EN 50122-1, multiplied by $2 \times \sqrt{2}$ and the direct component of the wave-form does not exceed the permissible direct voltage according to EN 50122-1.

The duration of the alternating voltage and the duration of the direct voltage is taken into account when deducing the permissible alternating voltage and direct voltage using the values given in EN 50122-1.

The combined peak value includes also the effects of higher frequencies. If the crest factor (crest factor = peak value divided by r.m.s. value) of the a.c. part of the combined peak value is larger than $\sqrt{2}$, the effects are taken into account.

In case an r.m.s. value is found for the alternating component, the crest factor is determined and the r.m.s. value of the alternating component as has been found is multiplied by a crest correction factor. The crest correction factor is the crest factor divided by $\sqrt{2}$. If the crest correction factor is smaller than 1, then it becomes equal to 1. The crest factor is the peak value of the voltage divided by the r.m.s. value of the voltage.

In case of simulations, usually frequency components are found without phase relation. In this case the peak value of the alternating component is determined by adding the peak values of the individual frequency components of the alternating component. Based on this peak value the crest factor and the crest correction factor are determined. In case phase information is available, this can be used.



Key

- 1 positive peak value relative to 0 V
- 2 absolute value of the negative peak value relative to 0 V
- 3 peak-to-peak value
- a* peak
- b* peak-peak

Figure B.1 — Definition of combined peak voltage

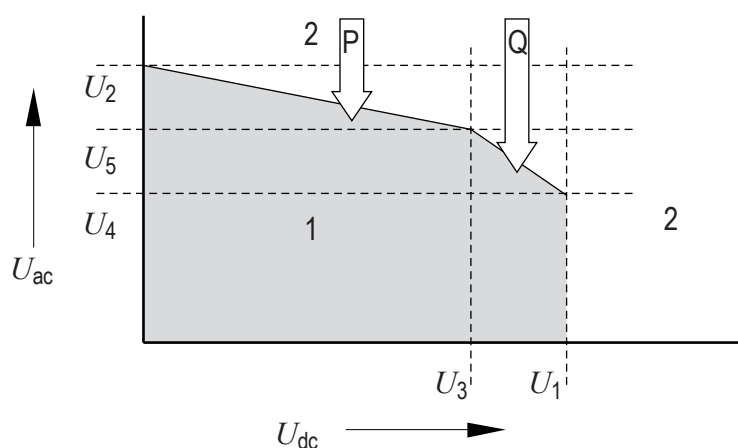
In general the three following conditions have to be complied with to fulfil the safety of persons for a combined touch voltage:

1. the r.m.s. alternating part taking into consideration the correction factor of the combined voltage has to be lower than the alternating voltage r.m.s. limit as given in EN 50122-1 for the applicable duration;
2. the direct part of the combined voltage is lower than the direct voltage limit as given in EN 50122-1 for the applicable duration;
3. the combined peak value of the combined voltage is lower than the alternating voltage limit multiplied with a factor depending on the time duration:
 - i. $t < 0,3 \text{ s}$ factor is $\sqrt{2}$;
 - ii. $t > 1,0 \text{ s}$ factor is $2\sqrt{2}$;
 - iii. $0,3 \text{ s} \leq t \leq 1,0 \text{ s}$ factor is determined using linear interpolation between the values mentioned above.

For a duration $t \leq 0,3 \text{ s}$ the peak value is used, for a duration $t \geq 1,0 \text{ s}$ the combined peak value is used for the analyses. In the interval $0,3 \text{ s} \leq t \leq 1,0 \text{ s}$ an interpolation between the peak value and the combined peak value calculated.

The permissible body and touch voltages are distinguished according the duration given in EN 50122-1. The permissible combined voltages are situated within the envelope shown in Figure B.2.

If the duration is longer than 1,0 s a peak-peak approach is used, leading to a horizontal line P in Figure B.2. For a duration shorter than 0,3 s a peak approach is used leading to a slope of line P equal to the slope of line Q. For the duration between 0,3 s to 1,0 s an interpolation is used.



Key

- 1 permissible
- 2 not permissible

Figure B.2 — Overview of permissible combined a.c. and d.c. voltages

In Figure B.2 the following abbreviations are used:

$$\alpha = 0 \quad t \geq 1 \text{ s}$$

$$\alpha = \frac{(U_{ac, \max} - U_{ac, 1,0})}{(U_{ac, 0,3} - U_{ac, 1,0})} \quad 0,3 \text{ s} \leq t \leq 1,0 \text{ s}$$

$$\alpha = 1 \quad t \leq 0,3 \text{ s}$$

$$U_1 = U_{dc, \max}$$

$$U_2 = U_{ac, \max}$$

$$U_3 = \frac{\sqrt{2} \times U_{ac, \max}}{(1 + \alpha)}$$

$$U_4 = \frac{2 \cdot U_{ac, \max}}{(1 + \alpha)} - \frac{U_{dc, \max}}{\sqrt{2}}$$

$$U_5 = \frac{U_{ac, \max}}{(1 + \alpha)}$$

where

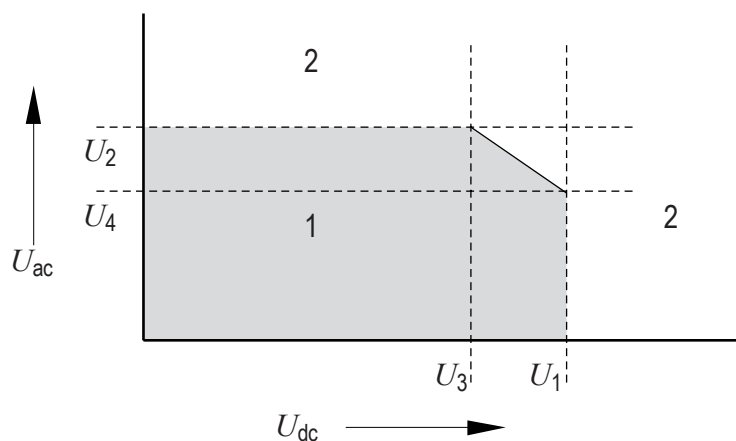
- $U_{dc, \max}$ is the maximum permissible d.c. voltage as given in EN 50122-1, for the applicable time duration;
- $U_{ac, \max}$ is the maximum permissible a.c. voltage as given in EN 50122-1, for the applicable time duration;
- $U_{ac, 0,3}$ is the maximum permissible a.c. voltage as given in EN 50122-1, for 0,3 s;
- $U_{ac, 1,0}$ is the maximum permissible a.c. voltage as given in EN 50122-1, for 1,0 s.

The slopes of the lines P and Q are the following:

Line P: $\text{slope} = S_P = \alpha \cdot \frac{-1}{\sqrt{2}}$

Line Q: $\text{slope} = S_Q = \frac{-1}{\sqrt{2}}$

As illustration an overview for alternating voltage in combination with direct voltage both with a duration $\geq 1,0$ s is shown in Figure B.3.

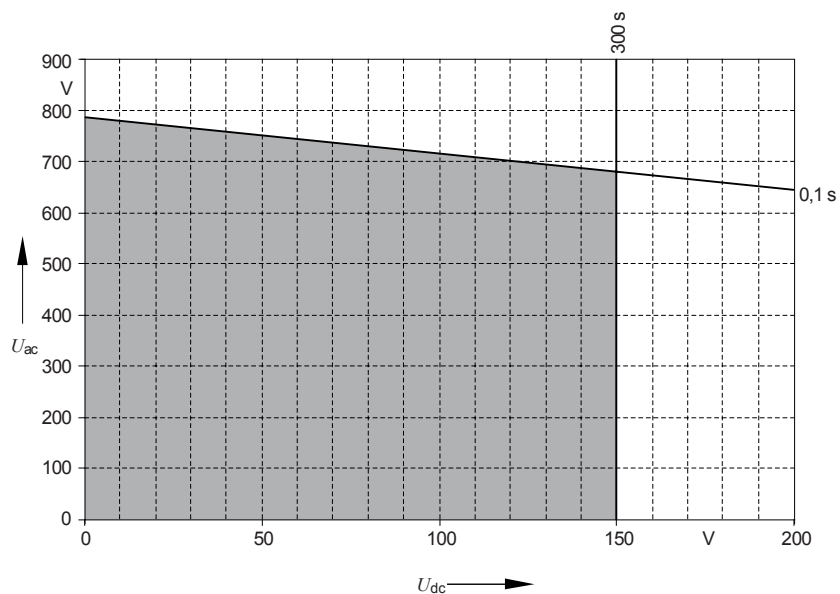


Key

- 1 permissible
- 2 not permissible

Figure B.3 — Overview of permissible voltages in case of a duration $\geq 1,0$ s both a.c. voltage and d.c. voltage

An example of the use of Figures 2 and 3 is shown in Figure B.4. For an a.c. voltage duration of 0,1 s and a d.c. voltage duration of 300 s combined voltages within the shaded area are permissible.



**Figure B.4 — Permissible voltages in case of
a duration 0,1 s a.c. voltage and a duration 300 s d.c. voltage**

Annex C (informative)

Analysis and assessment of mutual interaction

C.1 General

Both the a.c. system as well as the d.c. system shall be considered as sink and as source. For the sink, both (electro)technical systems as well as human beings are taken into consideration. Considering the mechanisms as given in Clause 5 the influence of a railway system on an adjacent system is determined, taking into account the applicable load and system configurations.

C.2 Analysis of mutual interaction

Analysis of the situation is not required when the distance is larger than the width of the zone of mutual interaction as described in Clause 6, unless there are indications that mutual interaction is possible. Analysis of the situation is required when the distance is smaller than 50 m.

C.3 System configurations to be taken into consideration

For a railway system as a minimum two cases are distinguished:

1. long-term conditions;
2. short-term conditions.

It is ascertained which long-term condition represent the maximum coupling between source and sink. The assessment of operating condition is based on the combination of traffic and electrical feeding which gives the worst coupling between the systems. Also it is ascertained which parts of the source and sink system need to be considered.

NOTE For the purpose of analysis, long-term conditions are associated with operation conditions and short-term conditions are associated with fault conditions or for example switching operations.

Annex ZZ (informative)

Coverage of Essential Requirements of EC Directives

This European Standard has been prepared under a mandate given to CENELEC by the European Commission and the European Free Trade Association and within its scope the standard covers all relevant essential requirements as given in Annex III of the EC Directive 96/48/EC (HSR), in Annex III of the EC Directive 2001/16/EC (CONRAIL) and in Annex III of the EC Directive 2008/57/EC (RAIL).

Compliance with this standard provides one means of conformity with the specified essential requirements of the Directive concerned.

WARNING: Other requirements and other EC Directives may be applicable to the products falling within the scope of this standard.

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IEC/TS 60479-1:2005, *Effects of current on human beings and livestock – Part 1: General aspects*

IEC/TS 60479-2:2005, *Effects of current on human beings and livestock – Part 2: Special aspects*

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