BS EN 50526-3:2016

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Railway application — Fixed installations — D.C. surge arresters and voltage limiting devices

Part 3: Application Guide

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National foreword

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European foreword

This document (EN 50526-3:2016) has been prepared by CLC/SC 9XC, "Electric supply and earthing systems for public transport equipment and ancillary apparatus (Fixed installations)", of CLC/TC 9X, "Electrical and electronic applications for railways".

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Introduction

This European Standard is divided into three parts.

Part 1 deals with metal oxide arresters without gaps for d.c. railway traction systems (fixed installations) and is based on EN 60099-4.

Part 2 deals with voltage limiting devices for specific use in d.c. railway traction systems (fixed installations).

Part 3 is a Guide of application of metal-oxide arresters and of voltage limiting devices.

1 Scope

This Application Guide supports the European Standards EN 50526-1 and EN 50526-2.

Guidance is offered on the following subjects:

– the selection and installation of surge arresters;

– the selection and installation of voltage limiting devices as VLD-O and VLD-F;

– the arrangement of the surge arresters and VLDs.

Because of differences in the established, proven methods, electric traction systems of nominal voltage d.c. 600 V – d.c. 750 V are treated separately from the systems at higher nominal voltages.

This Application Guide only applies to d.c. electrified traction systems

2 Normative references

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

EN 50122-1:2011, *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*

EN 50123-2:2003, *Railway applications - Fixed installations - D.C. switchgear - Part 2: D.C. circuit breakers*

EN 50123-7-1:2003, *Railway applications - Fixed installations - D.C. switchgear - Part 7-1: Measurement, control and protection devices for specific use in d.c. traction systems - Application guide*

EN 50124-1:2001, *Railway applications - Insulation coordination - Part 1: Basic requirements - Clearances and creepage distances for all electrical and electronic equipment*

EN 50163: 2004 , *Railway applications - Supply voltages of traction systems*

EN 50526-1:2012, *Railway applications - Fixed installations - D.C. surge arresters and voltage limiting devices - Part 1: Surge arresters*

EN 50526-2:2014, *Railway applications - Fixed installations - D.C. surge arresters and voltage limiting devices - Part 2: Voltage limiting devices*

EN 62305-2, *Protection against lightning - Part 2: Risk management.*

IEC 60050-195:1998, *International Electrotechnical Vocabulary - Chapter 195: Earthing and protection against electric shock*

IEC 60050-441:1984, *International Electrotechnical Vocabulary - Chapter 441: Switchgear, controlgear and fuses*

IEC 60050-604:1987, *International Electrotechnical Vocabulary. Chapter 604: Generation, transmission and distribution of electricity - Operation*

IEC 60050-811:1991, *International Electrotechnical Vocabulary - Chapter 811: Electric traction*

3 Terms and definitions

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

3.1
nominal voltage
$\mathbf{U_n}$
designated value for a system

[SOURCE: EN 50163:2004, 3.3]

3.2
highest permanent voltage
$\mathbf{U_{max1}}$
maximum value of the voltage likely to be present indefinitely

[SOURCE: EN 50163:2004, 3.4]

3.3
highest non-permanent voltage
$\mathbf{U_{max2}}$
maximum value of the voltage likely to be present for a limited period of time

[SOURCE: Adapted from EN 50163:2004, 3.5]

3.4
rated insulation voltage
$\mathbf{U_{Nm}}$
d.c withstand voltage value assigned by the manufacturer to the equipment or a part of it, characterising the specified permanent (over five minutes) withstand capability of its insulation

[SOURCE: EN 50526-1:2012, 3.4]

3.5
rated impulse withstand voltage
$\mathbf{U_{Ni}}$
impulse voltage value assigned by the manufacturer to the equipment or a part of it, characterising the specified withstand capability of its insulation against transient overvoltages

[SOURCE: EN 50526-1:2012, 3.5]

3.6
overvoltage
voltage having a peak value exceeding the corresponding peak value of the highest non-permanent voltage U_{max2}

[SOURCE: EN 50526-1:2012, 3.6]

3.7
transient overvoltage
short duration overvoltage of a few (up to 20 ms) milliseconds or less associated with a transient regime

Note 1 to entry: Two particular transient overvoltages are defined: switching overvoltage and lightning overvoltage.

[SOURCE: EN 50526-1:2012, 3.7]

3.8
switching overvoltage
U_{so}
transient overvoltage at any point of the system due to specific switching operation or fault

[SOURCE: EN 50526-1:2012, 3.8]

3.9
lightning overvoltage
transient overvoltage at any point of the system due to a lightning discharge

[SOURCE: EN 50124-1:2001,1.3.3.2.2]

3.10
surge arrester
device intended to limit the transient overvoltages to a specified level

[SOURCE: EN 50526-1:2012, 3.10]

3.11
metal-oxide surge arrester
arrester having non-linear metal-oxide resistors connected in series and/or in parallel without any integrated series or parallel spark gaps

[SOURCE: EN 50526-1:2012, 3.11]

3.12
continuous operating voltage of an arrester
U_c
designated permissible d.c. voltage value that may be applied continuously between the arrester terminals

[SOURCE: EN 50526-1:2012, 3.12]

3.13
rated voltage of an arrester
U_r
voltage by which the arrester is designated

Note 1 to entry: Because of the particular nature of the d.c. electrical installation dealt with, the rated voltage of a d.c. arrester coincides with the continuous operating voltage.

[SOURCE: EN 50526-1:2012, 3.13]

3.14
lightning impulse protection level
U_{pl}
the maximum residual voltage for the nominal discharge current

[SOURCE: EN 50526-1:2012, 3.15]

3.15
switching impulse protection level
U_{ps}
maximum residual voltage at the specified switching impulse current

[SOURCE: EN 50526-1:2012, 3.16]

3.16
charge transfer capability
Q_T
maximum charge per impulse that can be transferred during the charge transfer test and during the operating duty test

[SOURCE: EN 50526-1:2012, 3.17]

3.17
discharge current of an arrester
impulse current which flows through the arrester

[SOURCE: EN 50526-1:2012, 3.18]

3.18
nominal discharge current of an arrester
I_n
peak value of lightning current impulse which is used to classify an arrester

[SOURCE: EN 50526-1:2012, 3.19]

3.19
high current impulse of an arrester
peak value of discharge current having a 4/10 µs impulse shape which is used to test the stability of the arrester on direct lightning strikes

[SOURCE: EN 50526-1:2012, 3.20]

3.20
steep current impulse
current impulse with a virtual front time of 1 µs with limits in the adjustment of equipment such that the measured values are from 0,9 µs to 1,1 µs and the virtual time to half-value on the tail is not longer than 20 µs

[SOURCE: EN 50526-1:2012, 3.21]

3.21
lightning current impulse
8/20 µs current impulse with limits on the adjustment of equipment such that the measured values are from 7 µs to 9 µs for the virtual front time and from 18 µs to 22 µs for the time to half-value on the tail

[SOURCE: EN 50526-1:2012, 3.22]

3.22
direct lightning current impulse
impulse defined by the charge Q and the peak value of the current impulse I_{imp}

[SOURCE: EN 50526-1:2012, 3.23]

3.23
switching current impulse of an arrester
I_{sw}
peak value of discharge current having a virtual front time greater than 30 µs but less than 100 µs and a virtual time to half value on the tail of roughly twice the virtual front time

[SOURCE: EN 50526-1:2012, 3.24]

3.24
porcelain-housed arrester
arrester using porcelain as housing material, with fittings and sealing systems

[SOURCE: EN 50526-1:2012, 3.30]

3.25
polymer-housed arrester
arrester using polymeric and/or composite materials for housing

[SOURCE: EN 50526-1:2012, 3.31]

3.26
flashover
disruptive discharge over a solid surface

[SOURCE: EN 50526-1:2012, 3.44]

3.27
impulse
unidirectional wave of voltage or current which without appreciable oscillations rises rapidly to a maximum value and falls – usually less rapidly – to zero with small, if any, excursions of opposite polarity

Note 1 to entry: The parameters which define a voltage or current impulse are polarity, peak value, front time and time to half value on the tail.

[SOURCE: EN 50526-1:2012, 3.45]

3.28
voltage-limiting device
VLD
protective device whose function is to prevent existence of an impermissible high touch voltage

[SOURCE: EN 50122-1:2011, 3.1.20]

3.29
recoverable VLD
VLD that recovers after triggering

[SOURCE: EN 50526-2:2014, 3.2]

3.30
non-recoverable VLD
VLD remaining in its low resistance state permanently after triggering

[SOURCE: EN 50526-2:2014, 3.3]

3.31
welding-shut spark gap
voltage fuse
VLD which triggers by electrical discharge across a gap causing a permanent short-circuit by melting of metallic parts

[SOURCE: EN 50526-2:2014, 3.4]

3.32
rated current
I_r
maximum value of the direct current that may flow permanently through the VLD in specified environmental conditions

[SOURCE:EN 50526-2:2014, 3.5]

3.33
short time withstand current
I_W
current that a VLD can carry in closed status, during a specified short time under prescribed conditions of use and behaviour

[SOURCE: EN 50526-2:2014, 3.6]

3.34
breaking capacity
maximum current that a recoverable VLD can interrupt at a stated voltage

[SOURCE: IEC 60050-441:1984, 17-08]

3.35
residual voltage
U_{res}
a) peak value of voltage that appears between the terminals of an arrester during the passage of discharge current

b) value of voltage that appears between the terminals of the VLD during the passage of a specified current

[SOURCE: EN 50526-1:2012, 3.27] and [SOURCE: EN 50526-2:2014, 3.17]

3.36
structure earth
construction made of metallic parts or construction including interconnected metallic structural parts, which can be used as an earth electrode

[SOURCE: EN 50122-1:2011, 3.2.4]

3.37
open connection
connection of conductive parts to the return circuit by a voltage-limiting device which makes a conductive connection either temporarily or permanently if the limited value of the voltage is exceeded

[SOURCE: EN 50122-1:2011, 3.2.12]

3.38
return circuit
all conductors which form the intended path for the traction return current

EXAMPLE Conductors may be:

– running rails,

– return conductor rails,

– return conductors,

– return cables.

[SOURCE: EN 50122-1:2011, 3.3.1]

3.39
rail potential
U_{RE}
voltage occurring between running rails and earth

[SOURCE: EN 50122-1:2011, 3.3.7]

3.40
(traction) substation
installation to supply a contact line system and at which the voltage of a primary supply system, and in certain cases the frequency, is transformed to the voltage and the frequency of the contact line

[SOURCE: EN 50122-1:2011, 3.4.2]

3.41
(traction) switching station
installation from which electrical energy can be distributed to different feeding sections or from which different feeding sections can be switched on and off or can be interconnected

[SOURCE: EN 50122-1:2011, 3.4.3]

3.42
normal operation
operation without fault condition on the line

Note 1 to entry: In this standard normal operation includes also degraded mode (loss of one or several substations)

3.43
fault (or fault condition)
non intended condition caused by short-circuit. The time duration is terminated by the correct function of the protection devices and circuit breakers

Note 1 to entry: For the relevant fault duration the correct operation of protection devices and circuit breakers is taken into account.

[SOURCE: Adapted from EN 50122-1:2011, 3.4.5]

3.44
internal overvoltage
an overvoltage in the system resulting from switching or from a fault in the system itself

[SOURCE: IEC 60050-604:1987, 03-31]

3.45
short-circuit
accidental or intentional conductive path between two or more conductive parts forcing the electric potential differences between these conductive parts to be equal to or close to zero

[SOURCE: IEC 60050-195:1998, 04-11]

3.46
stray current
part of the current caused by a d.c.-traction system which follows paths other than the return circuit

[SOURCE: Adapted from EN 50122-1:2011, 3.6.3]

3.47
overhead contact line
OCL
contact line placed above (or beside) the upper limit of the vehicle gauge and supplying vehicles with electric energy through roof-mounted current collection equipment

[SOURCE: IEC 60050-811:1991, 33-02]

3.48
conductor rail
contact line made of a rigid metallic section or rail, mounted on insulators located near the running rails

[SOURCE: EN 50119:2009, 3.1.7]

3.49
overhead contact line zone
OCLZ
zone whose limits are in general not exceeded by a broken overhead contact line

[SOURCE: EN 50122-1:2011, 3.5.9]

3.50
current collector zone
CCZ
zone whose limits are in general not exceeded by an energised collector no longer in contact with the contact line or broken collector and its fragments

[SOURCE: EN 50122-1:2011, 3.5.10]

4 General considerations

4.1 General

Surge arresters are intended to protect power equipment from the lightning overvoltages. A surge arrester can be used also in order to protect electronic equipment against high transient voltages in the circuits to which the equipment is connected. See EN 50526-1 for the product specification.

VLDs are intended to protect persons from impermissible touch voltages between conductive parts caused by train operating currents or faults. When selecting a VLD, it should be considered whether the required function is VLD-F, or VLD-O or both as described in EN 50122-1. This is a question for the system design. See EN 50526-2 for the product specification.

4.2 Application of surge arresters

4.2.1 General

The contact lines of electric railways are exposed to direct and to indirect lightning overvoltages. These overvoltages may cause flashover of the line insulation and, travelling along the lines, may enter the supply substations and stress or even damage the insulation of the equipment inside. Overvoltages may also appear on the track and, travelling along it, stress the insulation of the electronic equipment connected to it.

The insulation of the substation equipment is critical, as flashover of such insulation in most cases causes a permanent outage of the substation. Also the insulation of the equipment connected to the track is critical as it is not self-restoring. Such equipment should be protected by surge arresters of such characteristics as to reduce the overvoltages below its insulation level.

Flashover of the line insulation is in general non critical. The flash over initiates a short circuit of the power supply system which is then cleared by the protective circuit breaker. In most cases the insulation is self-restoring and the line can be re-energized after a short time (a few seconds) following the tripping

Therefore, line insulation does not require to be protected by surge arresters except in special cases: e.g. cable terminations connected to the line, discontinuities along the line in regions with a very high flash density, very high short circuit follow-through currents able to damage the insulators, etc.

In order to protect the insulation it is necessary to coordinate properly the characteristics of the protecting surge arresters with those of the protected insulation. For this purpose the following information is necessary as a minimum:

– Lightning impulse withstand level of the equipment to be protected (see 4.2.2);

– Characteristics of the lightning overvoltages (see 4.2.4);

– Protection level of the arrester (see 6.5);

– Charge transfer capability of the arrester (see 6.6).

The protection is effective if the protection level provided by the arrester is lower with enough margin than the lightning impulse withstanding level of the equipment to be protected.

In choosing the arrester, knowledge is necessary also of the maximum internal overvoltages (see 4.2.3) as it is necessary to make sure that the charge transfer capability of the arrester is not exceeded.

4.2.2 Insulation level of equipment to be protected

For the equipment powered by the contact line, Table A.2 in EN 50124-1:2001 gives information on minimum values of the rated impulse voltage (U_{Ni}). In general, for equipment connected to the return circuit inside the substations, the insulation level is assumed to be the same as for circuits directly connected to the contact line. For bonding cables and related items no standard impulse withstand voltage is available.

4.2.3 Internal overvoltages

For equipment powered by the contact line:

– Annex A in EN 50163:2004 gives information on the amplitude and duration of the voltage that may appear on the contact line and stress the connected equipment.

– the highest switching overvoltage may be assumed to be 3 - 4 times the nominal voltage as the arc voltage in the circuit breaker is limited to four times U_n (see 5.7 of EN 50123-2:2003).

For equipment connected to the track a voltage as a function of the time as indicated in Table 6 in EN 50122-1:2011 may be assumed.

4.2.4 Lightning Overvoltages

Traction systems can be treated in the same way as medium voltage distribution systems with respect to overvoltages and insulation co-ordination.

Lightning parameters are derived from statistical analysis of worldwide lightning measurements. The most frequently occurring negative cloud-to-ground flashes have current peak values between 14 kA (95 % probability) and 80 kA (5 % probability). With a probability of 50 %, the following values are reached or exceeded (see for instance Cigré TB 287):

– Current peak value: 30 kA

– Rise time: 5,5 µs

– Time to half value: 75 µs

Extreme lightning surges can reach peak values up to 200 kA, with half-time values of 2 000 µs. A peak value of 20 kA with a probability of 80 % is often used in the standardisation work, and for test and co-ordination purposes for surge arresters. This standardized nominal lightning current has a rise time of 8 µs and a half time of 20 µs (wave shape 8/20). Other standardized currents are the high current impulse with the wave shape 4/10 µs and peak values up to 200 kA, and the switching current impulse with 30/60 µs wave shape and peak values up to 2 kA.

A specific wave shape 10/350 µs for direct lightning is also defined (see EN 50526-1). Normally, there is a flashover at each pole (see below) leading after a few spans to an 8/20 µs wave shape, so that this wave shape is finally used for classifying surge arresters.

In case of a direct lightning strike into the contact line, the charge flows in the form of two equal current waves in both directions, starting from the point of strike. A voltage wave is accompanied by the current wave due to the surge impedance of the line.

Typical values for the surge impedances of overhead lines in d.c. traction systems are 460 Ω for non-catenary overhead contact lines and 380 Ω for catenary overhead contact lines. For conductor rails a value of 160 Ω can be used.

NOTE For other specific cases calculation methods are available in the literature.

Considering the peak value of 30 kA, as mentioned above, and a surge impedance of 460 Ω, a very high transient overvoltage occurs, with a steepness of about 1 250 kV/µs. None of the equipment in d.c. railway systems up to 3 000 V is insulated for such voltage stresses. Therefore, surge arresters have to be used to limit the transient overvoltages from lightning according to the rules of insulation co-ordination.

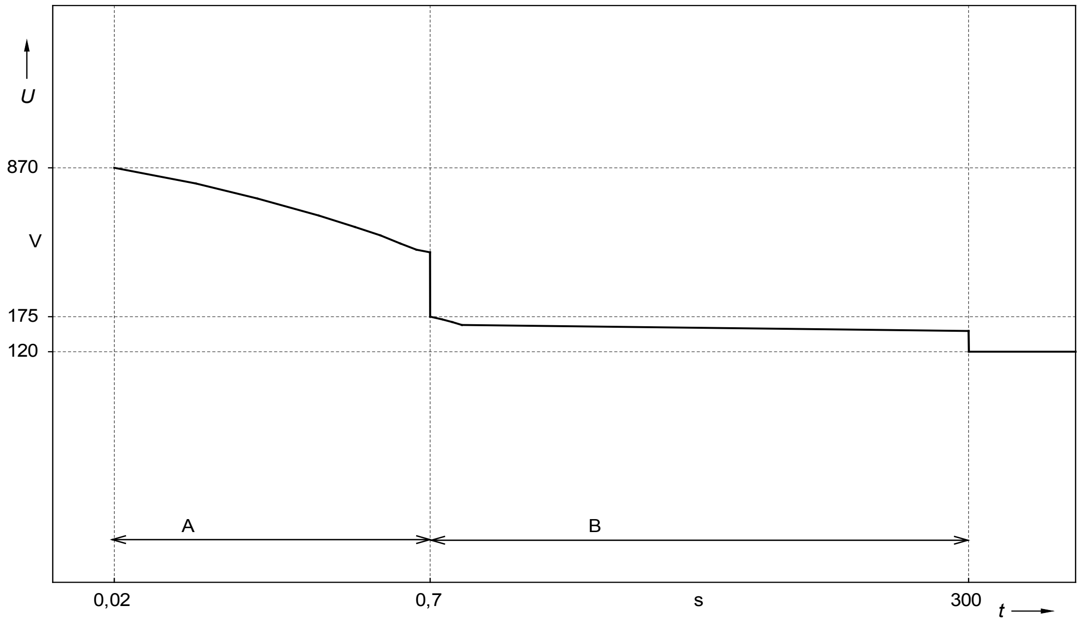
Besides the regional exposure to lightning, the frequency of lightning strikes depends on the topography and the structural design of the line (see EN 62305-2). In particular, the frequency of lightning strikes is relatively high if there are big crossing areas, bridges, viaducts and spacious operating areas. It is to be noted that lightning protection can always only cover a certain percentage of all possible lightning strikes and mainly depends on operational and economic aspects (see EN 62305-2).

4.3 Application of VLDs

4.3.1 General

As stipulated by EN 50122-1, a VLD operates in such a way as to bond the return circuit of d.c. railway systems to the earthing system or the exposed conductive parts, in order to suppress impermissible touch voltages in normal operation or in fault condition. The voltages admissible in the track as defined by EN 50122-1 are indicated in Figure1.

For general requirements for the application of VLDs refer to EN 50122-1:2011, Annex F.



Key

A short-term protection

B long-term protection

t time duration (s)

Figure 1 – Permissible touch voltages in d.c. traction systems according to EN 50122-1

4.3.2 Short term protection

The short term protection aims at protecting people and equipment against dangerous accessible voltages that can arise in fault condition, such as the fall of a broken contact wire. VLDs type F ensure this function: the VLD-F function is required when the source of the impermissible voltage is the voltage on the contact line, when a fault occurs, and the risks are of electric shock by indirect contact as described in EN 50122-1.

The VLD-F need a short-time current capability to carry the expected short time current, especially when the fault location is close to the substation. A VLD-F needs not interrupt the part of the fault current which flows through it, as line circuit breakers are employed to limit the risks from that current.

An A2 arrester may be put in parallel to a VLD. In this case the A2 arrester provides the protection of the VLD against the lightning overvoltages while the VLD protects against impermissible touch voltages. Additionally, the VLD may reduce the required charge transfer capability of the A2 arrester.

4.3.3 Long term protection

The long term protection provided by a VLD-O corresponds to protection against impermissible touch voltages that may arise in normal operation due to the train traffic and to the fact that permanent equipotential bonding should not be provided because of the risks from damage to assets by stray current, as described in EN 50122-2. A VLD-O should be able to interrupt the current that flows in it, in order to minimise the risks from stray current. VLD-Os require a long term current capability.

4.3.4 Selection of VLD-F or VLD-O

A single VLD can fulfil both functions; VLD-F and VLD-O, if attention is paid to the relevant characteristics when the device is selected.

To limit the risks from stray current, all of these devices (VLD-F and VLD-O) offer better performance if they are recoverable (Classes 2, 3 and 4) than if they are non-recoverable (Class 1).

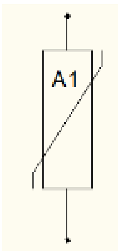
Definite selection and application of appropriate Class is subject to specific requirements depending on several factors like: location, type of system, object to be protected, etc.

NOTE Classes of VLDs are defined in EN 50526-2:2014.

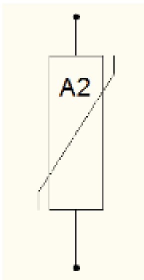
5 Symbols for surge arresters and VLDs

The following symbols should be used to designate the arresters and voltage limiting devices, whatever the technology used for the device is:

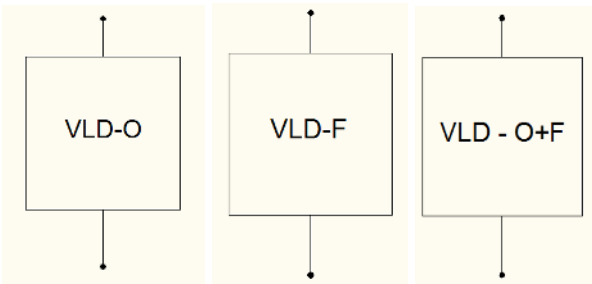
5.1
A1 arrester



5.2
A2 arrester

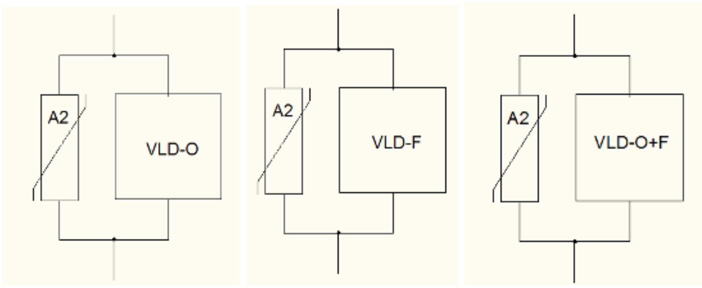


5.3
Voltage Limiting Device



5.4

Combination of VLD and A2 arrester



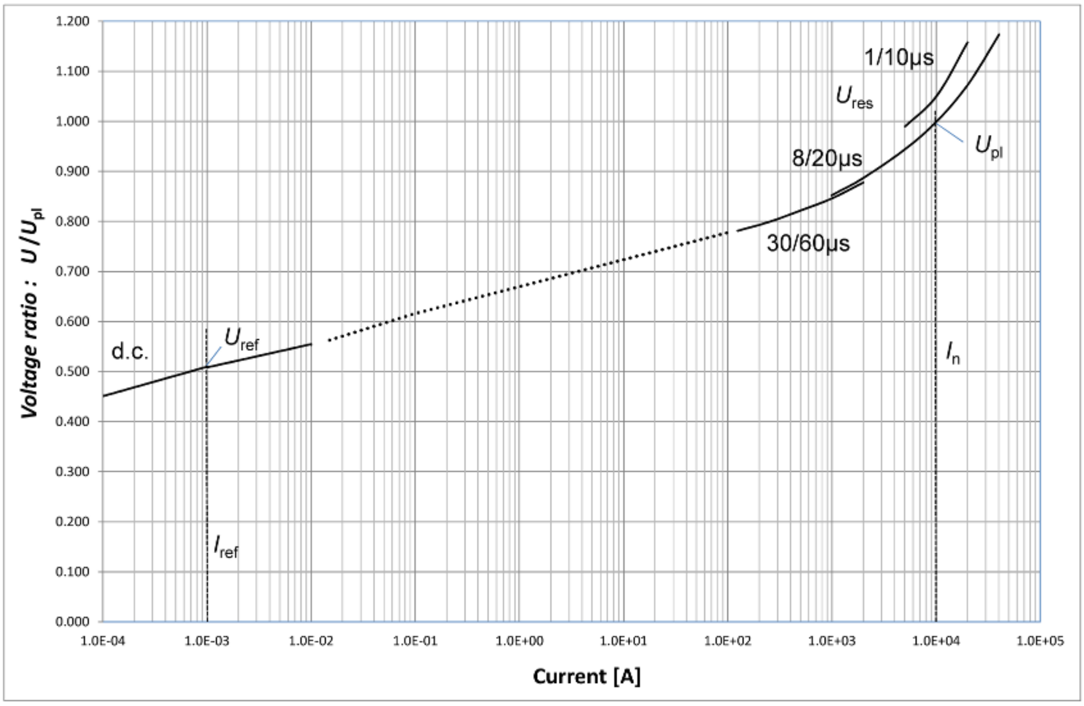
NOTE This symbol of arrester A1 also refers to a varistor, but is used to keep consistency with the symbols used in EN 50526-1.

6 Guideline for Surge Arresters

6.1 General

6.1.1 Electrical characteristics

Figure 2 shows the typical U-I characteristic of a metal oxide arrester measured by applying d.c. currents and current impulses of different wave shapes.



Key

U_{res} Residual voltage;

U_{pl} Lightning impulse protective level;

U_{ref} Reference voltage,

I_{ref} Reference current;

I_n Nominal discharge current.

Figure 2 – Typical residual voltage of a metal oxide arrester as a function of the current

Typical values of the lightning protective levels (U_{pl}) and of the switching protective levels (U_{ps}) depending on the discharge current and on the wave form are indicated in Table 1 as ratio to the continuous operating voltage, 0,29 kV ≤ U_c ≤ 5 kV.

Table 1 – Typical lightning and switching protective levels of d.c. metal oxide arresters.

Class	**U_{pl}/U_c**		**U_{ps}/U_c**	
	typical values	at	typical values	At
DC-A	2,5 to 3,1	10 kA - 8/20 μs	2,0 to 2,5	500 A - 30/60 μs
DC-B	2,3 to 2,5	10 kA - 8/20 μs	2,0 to 2,2	1 000 A - 30/60 μs
DC-C	2,4 to 2,5	20kA - 8/20 μs	2,0 to 2,2	2 000 A - 30/60 μs

6.1.2 Housing

The active part of d.c. surge arrester is made of MO resistor elements enclosed in a housing.

The main requirements of the housing are:

– sealing against moisture ingress;

– mechanical strength;

– voltage withstand at lightning or switching transients, to prevent flashovers;

– creepage distance, to prevent flashovers;

– performance under polluted conditions;

– pressure relief under overload conditions;

– conduct heat from the metal oxide resistor elements to the environment.

6.1.3 Porcelain-housed surge arresters

The active part of the arrester is placed in a porcelain insulator with terminations on both ends. The gap between active part and inner wall of the housing may be completely or partly filled with gas or by other material. The gas in these arresters typically is nitrogen or (synthetic) air. Usually pressure relief devices are provided which ensure that the housing will not break violently after puncture or flashover of the active part due to energetic overload. Special care about safety considerations shall be taken for designs without pressure relief devices.

Surge arresters with a housing from epoxy-resin behave mechanically like porcelain-housed arresters, because epoxy resin is a brittle material, and shall be treated and tested as porcelain-housed surge arresters.

6.1.4 Polymer-housed surge arresters

A variety of different designs has been developed, the main types of which are according to the following basic design principles:

a) "Tube design": The composite housing is formed from a tube of fibre glass reinforced plastic (FRP) covered by outer weather sheds from polymeric material with terminations on both ends. The outer weather sheds are either directly moulded to the tube or drawn as individual parts. This design has a sealing system and a pressure relief device which ensures that the housing will not break violently after puncture or flashover of the active part due to energetic overload. The internal design is similar to porcelain-housed arresters with an inner gas volume.

b) "Wrapped design": The housing is directly applied to the stack of metal oxide resistor elements without an intended gas volume inside. The mechanical supporting part of the housing is formed by a wrapped FRP structure with terminations on both sides and outer weather sheds from polymeric material.

c) "Cage design": The stack of metal oxide resistor elements is clamped by FRP loops or rods or bands at high mechanical tension forces. The metal oxide resistor elements act as part of the mechanically supporting structure and the FRP elements form an open cage. The outer weather sheds are directly moulded to the modules. The housing is without intended gas volume inside.

The outer part of a polymeric housing, which is exposed to the environment, may be made from different kinds of materials, such as EPDM (ethylene-propylene-diene-monomer), EVA (ethylene-vinyl-acetate) or SIR (silicone rubber). In most cases, these polymeric materials are doped by chemicals or filled by fillers in order to provide sufficient resistance to environmental impact. Most important characteristics are hydrophobicity (the ability to repel water) and tracking and erosion resistance.

Table 2 – Some characteristics of porcelain-housed and polymer-housed arresters

porcelain-housed surge arrester	**polymer-housed surge arrester**
high weight	low weight
brittle material, sensitive to mechanical shocks	flexible outer sheds, tolerant to mechanical shocks
cleaning of polluted housings necessary	no cleaning of polluted housing necessary
medium behaviour at polluted environment	excellent behaviour at polluted environment, hydrophobic behaviour

6.2 Systems and equipment to be protected by surge arresters

It is recommended to apply surge arresters in substations, at sectioning posts and at specific points along the contact line system to protect the connected equipment from transient overvoltages (see Figures 3 and 4).

The terminations of the insulated cables connected to the contact line system and the electronic apparatus connected to the return pole of the rectifier in the substations should be protected by surge arresters.

Surge arresters may also be installed between the OCL system and earth where discontinuities in the line are present and reflections of the overvoltage waves may occur, for example:

– at each feeding switch-disconnector or disconnector;

– along the line, at both sides of a normally open switch-disconnector or disconnector (bridging a section-insulator);

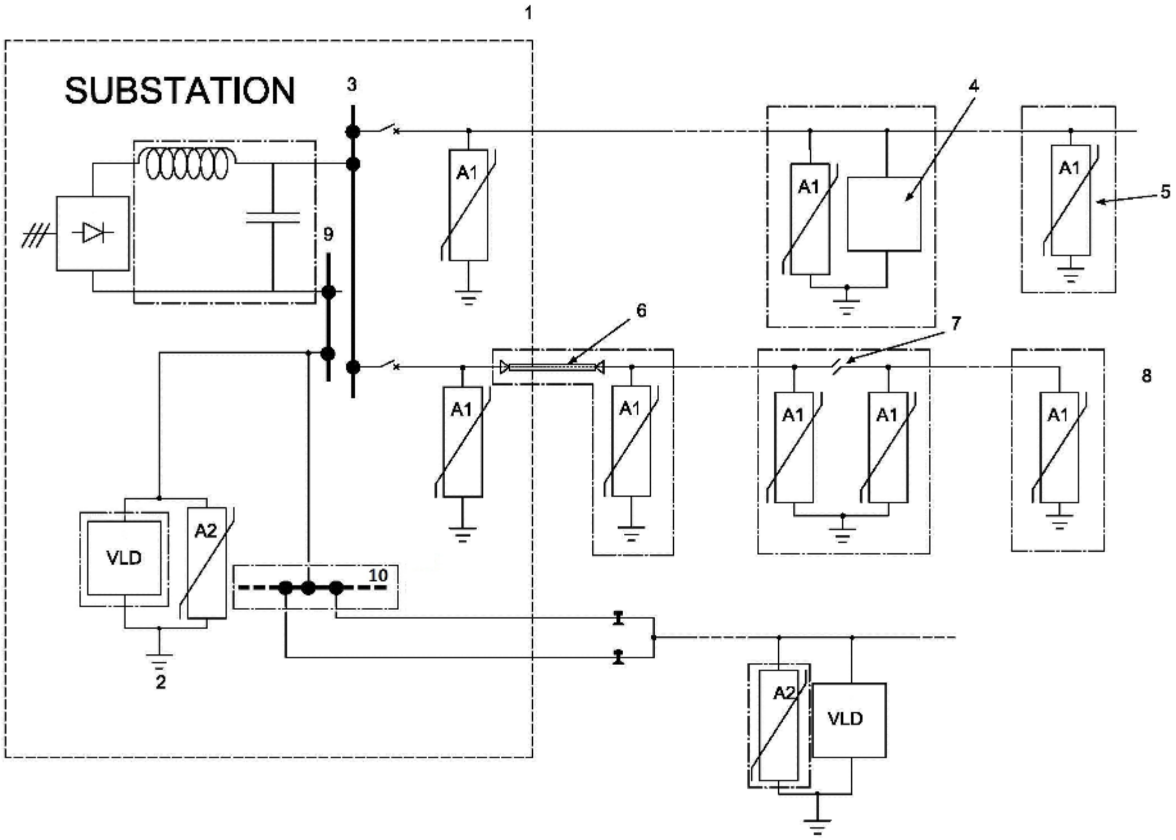
– along the line, at a normally closed switch-disconnector or disconnector (bridging a section-insulator);

– at the ends of a section;

– at power demand points (e.g. for switch heating).

For track sections with frequent lightning strikes, for instance on bridges or on elevated lines, additional arresters could be applied for example, at each group of tensioning devices (at about 1,5 km interval).

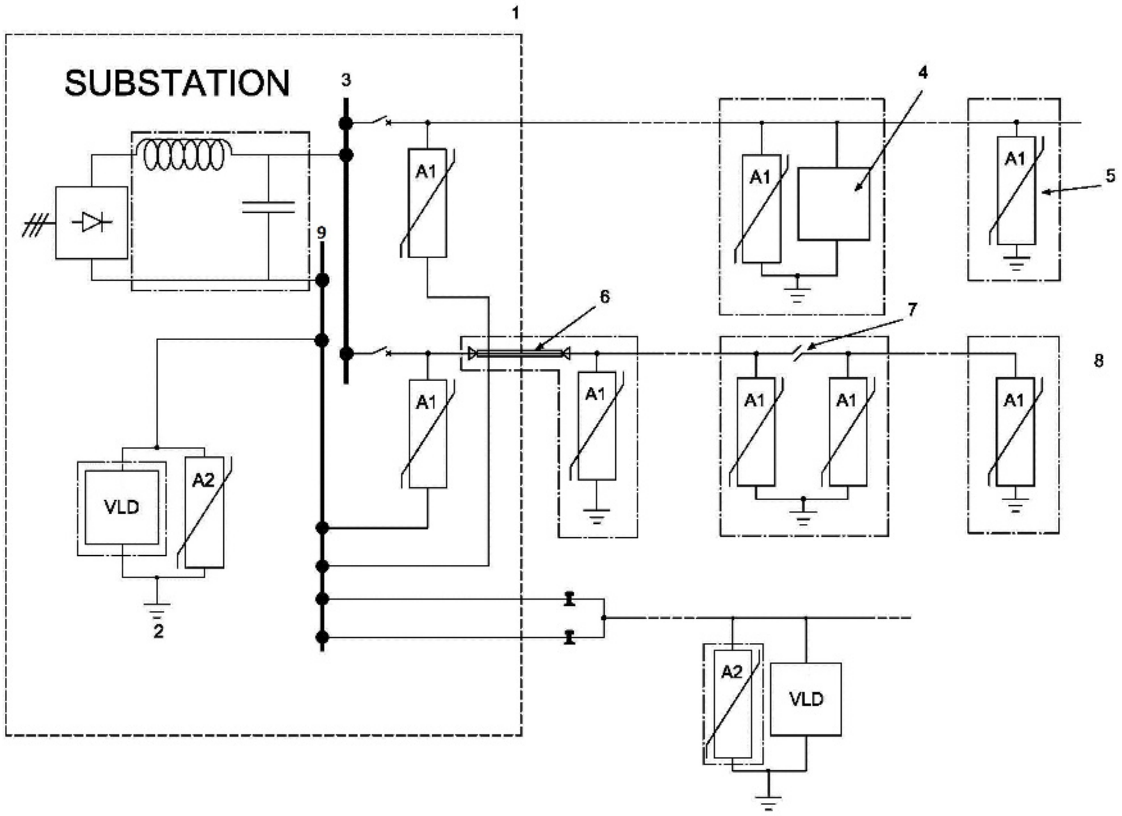
Figure 3 and Figure 4 show two possible schemes of application of surge arresters for protection of d.c. traction equipment. Figure 3 shows a scheme where the arresters (A1) are connected line to earth. A surge arrester (A2) may also be applied if necessary between the return circuit and the earth in the substation and along the lines to protect the equipment connected to the return circuit. The scheme described in Figure 4 consists of surge arresters (A1) connected line to the return circuit, of arresters (A1) connected line to earth along the line and of an arrester (A2) connected between return conductor and earth. According to mathematical simulations the scheme shown in Figure 3 results in a better performance as it provides better overvoltage protection if, for arrester A1, the same characteristics are applied. Another advantage is that in the usual layout of the substation no negative conductor is available at the outgoing feeder; applying scheme shown in Figure 3 does not require any change of the usual substation layout.



Key

— · —	optional (present in some national applied practice)
1	limit of the substation
2	substation earth
3	main busbar
4	equipment connected to the line protected by arrester A1
5	on bridges or on elevated lines
6	insulated cable
7	section insulator
8	end of section
9	return busbar
10	collector

Figure 3 – Scheme of application of surge arresters (preferred in 1,5 and 3 kV systems)



Key

_ . _	optional (present in some national applied practice)
1	limit of the substation
2	substation earth
3	main busbar
4	equipment connected to the line protected by arrester A1
5	on bridges or on elevated lines
6	insulated cable
7	section insulator
8	end of section
9	return busbar

Figure 4 – Alternative scheme of application of surge arresters

In both schemes arrester A2 may be connected in parallel with (or be integrated into) a voltage limiting device (EN 50526-2) applied to provide protection of the persons (limiting the touch voltages).

Arresters A1 may have different characteristics due to different requirements as: indoor or outdoor, arrester Class, etc.

Three different Classes of surge arresters with increasing charge transfer capability are specified in EN 50526-1 and shall be selected according to the needs of the d.c. system.

This Application Guide does not deal with the case of poles isolated from earth and connected to the return circuit.

NOTE The VLD and the arrester A2 in the substation shown in Figure 3 and 4 are not applied for d.c. 750 V systems, according to some national practices. In d.c. 750 V systems the application of A2-arresters is recommended in substations feeding sections above ground and also in the first substation behind a tunnel mouth (where the track changes from above ground to tunnel).

6.3 Nominal discharge current I_n

The nominal discharge current is used in several type tests. The value is determined by selecting a certain arrester Class, and fixed by the needed energy/charge transfer capability during switching and during lightning as indicated hereinafter.

Formula (1) shows that a nominal discharge current of the arrester I_n =10 kA is adequate, unless it is necessary to consider lightning strikes to the contact line very close to the arrester. If high levels of reliability are necessary, arresters rated at I_n = 20 kA, may be applied, for example for arresters connected to the poles along the line, exposed to direct lightning strikes.

Contrary to what happens for the A1 arresters, A2 arresters may be stressed by direct lightning current. The test described in Annex B in EN 50526-1:2012 may be appropriate.

The following Formula (1) gives the expression of the current through an arrester in a substation at the end of a line for a travelling wave of an amplitude *U*.

$$I_a = \frac{(2U - U_p)}{Z} \qquad (1)$$

where

I_a = arrester current;

U = magnitude of the incoming voltage;

U_p = residual voltage across the arrester;

Z = surge impedance of the line.

In most of the cases, as the lightning strikes the line, far from the arrester location , the amplitude of the incoming overvoltage, U, is limited by the flashover voltage of the line insulators and the current I_a drawn by the arrester is relatively low, much lower than the lightning current magnitude. In the very rare event of lightning striking the line just in the span having the arrester at one terminal (a direct lightning strike to the arrester terminal is also possible) the value of incoming voltage, U, may be much higher than the flashover voltage of the line insulators and the current I_a through the arrester may be very high.

EXAMPLE Application of Formula (1) above, with U = 100 kV, U_p = 10 kV, Z = 460 Ω, results approximately in I_a = 0,4 kA.

NOTE Surge arrester stresses are covered by the type tests “charge transfer test” (demonstration of charge transfer capability) and “operating duty test” (including ageing of metal oxide resistors, application of 20 times nominal discharge current and 2 times high current impulse) see 6.4 and 6.5 respectively in EN 50526-1:2012.

6.4 Selection of Continuous Operating Voltage

6.4.1 Continuous operating voltage U_c for arresters A1

For the arresters to be connected to the contact line voltage the minimum value of U_c shall be equal to or higher than the highest non-permanent voltage U_{max2} as defined by EN 50163:2004, Table 1.

$$U_c \geq U_{max2} \qquad (2)$$

Table 3 gives minimum values of U_c for the standardized nominal voltages

Table 3 – Minimum value of Uc

Nominal voltage U_n V	Minimum value of $U_c = U_{max2}$ V
750 1 500 3 000	1 000 1 950 3 900

6.4.2 Continuous operating voltage U_c for arresters A2

For an arrester A2, to be connected to the return circuit as shown in Figure 3 and Figure 4, the minimum value of U_c should be such that the arrester may withstand the maximum U(t) that may appear in the location for the specific application taking into account the functionality of the VLD possibly present in parallel.

According to the experience the minimum values of U_c indicated in Table 4 are recommended. The values in the Table refer to the case of absence of a VLD.

Table 4 – Recommended minimum values of U_c of A2 arresters

U_n V	U_c V
750	300
1 500	400
3 000	500

In case a VLD is connected in parallel to the A2 arrester other values of U_c may be selected according to the triggering characteristics of the VLD. It is recommended that, for the specific cases, calculations and/or measurements of the voltages on the return circuit in operational and switching conditions be performed before a decision is taken.

At heavy lightning strikes the discharge capacity of pole-mounted arresters A1 can be exceeded and a follow-through current driven by the contact line voltage can flow through the arrester and via the pole to earth and to the track return circuit. The earth resistance of the pole and the bedding resistance between earth and return circuit limit this current to a value, which cannot be detected by the line protection device as fault current. This leads to a continuous current flow with the pole being energized at contact line voltage. In this case a VLD between pole and track return circuit can reduce the resistance of the fault circuit and cause the line circuit breaker in the substation tripping.

NOTE For light railways an A2 arrester is sometimes used without a VLD in parallel. The U_c of such an arrester does not exceed the U_c in Table 4 but is equal to or higher than the permissible permanent touch voltage (U_c = 120 V to 300 V). Due to the low U_c the breakdown of the A1 arrester causes a current to flow through the A2 arrester and causes tripping of the protective circuit breaker. This current usually exceeds the short-time current carrying capacity of the A2 arrester and after such a fault both the A1 arrester and the A2 arrester need to be replaced.

6.5 Protective level of A1 and A2 arresters.

It is to be considered that the choice of U_c determines the U-I characteristic of the arrester of a given design and thus the protective characteristics. In the following it is assumed that the U_{pl} is in between 2,25 and 3 times U_c depending on the arrester design.

EN 50124-1 specifies values for:

– the rated insulation voltage (U_{Nm}) of the equipment directly connected to the OCL system (it states that for these circuits U_{Nm} is equal or higher then U_{max1});

– the rated impulse withstand voltage (U_{Ni}) in Table A.2;

– the creepage distances necessary for the pollution levels.

The overvoltage categories are defined in 2.2.2.1 of EN 50124-1:2001. In this respect it is to be mentioned that, for OCLs (A1 arresters) the OV4 category is recommended in all cases except for protected situations, such as tunnels and urban transportation systems, where equipment of OV3 could have been installed.

NOTE 1 For the A2 arresters, connected to the return circuit, the Table A.2 of EN 50124-1:2001 is not applicable: it is only for circuits connected to the contact line.

As a general rule in order to guarantee an effective protection it has to be verified that $U_{pl} < U_{Ni}$ (Table A.2 of EN 50124-1:2001).

Because of the travelling wave phenomena in the connections in between the arrester and the protected equipment, a margin of 25 % to 40 % should be kept in between U_{pl} and U_{Ni}. Then the protected equipment is well coordinated with the arrester if Formula (3) is satisfied.

$$U_{Ni} > K \times U_{pl} \qquad (3)$$

in which

K =1,25 to 1,4

NOTE 2 The factor K takes into account the difference that may exist between the residual voltage across the arrester, U_{pl}, and the voltage stressing the protected equipment due to the length of the connections in between and of the travelling wave phenomena through the connections above. A formula in the literature [2] provides the following value for the factor K:

$$K = 1 + \frac{2 \times S \times d}{c \times U_{pl}} \qquad (4)$$

Where:

S = steepness of the incoming overvoltage (kV/μs);

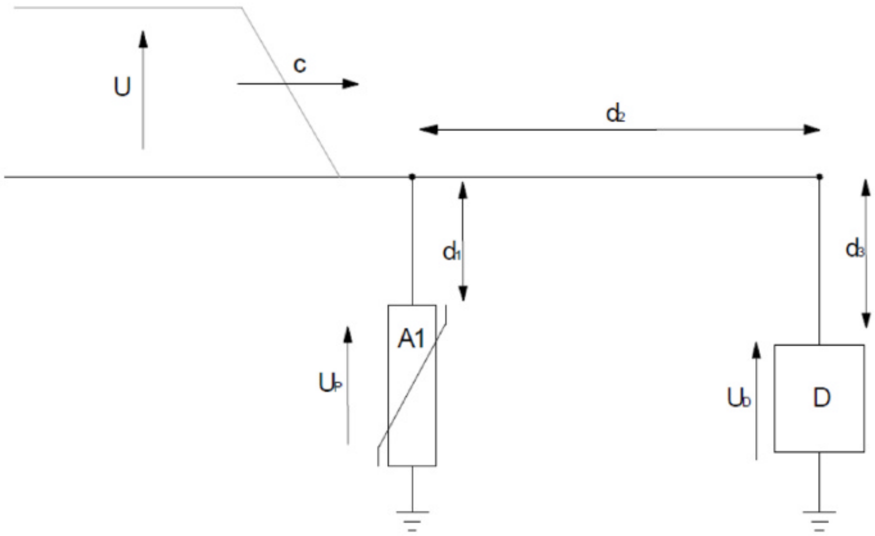
d = length of the connections between the arrester and the protected equipment (m);

c = speed of the light = 300 m/μs.

As an example of application of the formula above, if S = 30 kV/μs, d = 15 m, U_{pl} = 10 kV, then K = 1,3.

In conjunction with Formula (4) it is useful to define the "protected distance" as the maximum separation, d_M, between an arrester with a given lightning protective level, U_{pl}, and an insulation of given impulse withstand voltage, U_{Ni}, (see Figure 5) such that U_{Ni} is greater than the maximum overvoltage of given steepness, S

$$d_M = \frac{c}{2 \times S} \cdot \left(U_{Ni} - U_{pl}\right) \qquad (5)$$



Key

d total length of the connections in between the arrester and the protected equipment = d1+d2+d3 < dM

U_{pl} protective level of the surge arrester

U_D amplitude of the overvoltage stressing the apparatus

U_p residual voltage across A1 arrester

U overvoltage amplitude

S front steepness

Figure 5 – Overvoltage travelling at the speed c along a line terminating onto the device D protected by the surge arrester A1

As a consequence, since, according to Table 1, U_{pl} = (2,3 to 3,1) U_c , Formula (6) applies:

$$U_{Ni} > (1,25 \text{ to } 1,4) \times (2,3 \text{ to } 3,1)\, U_c \tag{6}$$

Thus U_c is such that:

$$U_c \leq \frac{U_{Ni}}{2,9 \text{ to } 4,3} \tag{7}$$

by combining Formula (7) with Formula (2) it is obtained that, in the case of a properly chosen arrester A1, Formula (8) applies.

$$U_{\max 2} \leq U_c \leq \frac{U_{Ni}}{2,9 \text{ to } 4,3} \tag{8}$$

Any value of U_c complying with Formula (8) ensures that a good coordination with the protected insulation is achieved. However, although a lower value of U_c provides a better protective effect, it is at the expense of an increased charge transfer capability requirement In some cases this fact may suggest to increase the value of U_c within the limits indicated by Formula (8).

6.6 Charge transfer capability

6.6.1 General

The energy, W, dissipated in the arrester during the flow of the current can be estimated as:

$$W = \int U \times I \times dt \approx U_{pl} \times \int I \times dt = U_{pl} \times Q_{imp} \quad (9)$$

where

U_{pl} is the lightning protective level (EN 50526-1);

Q_{imp} is the charge flowing through the arrester;

I is the current as a function of the time.

Table 5 gives examples of the charge Q_{imp} for several wave-shapes and current amplitudes.

Table 5 – Example of charge associated to the flow of a current of a given shape and amplitude through an arrester

Waveshape	Current amplitude I_{imp} (kA)	Charge Q_{imp} (As)
4/10 μs	100	1
8/20 μs	20	0,4
10/350 μs	15	7,5
Long duration current impulse (3,75 ms)	2 (Class DC-C)	7,5

The energy, W, dissipated in the arrester during the flow of a current associated with a switching overvoltage may be estimated as:

$$W = \int U \times I \times dt \approx U_{ps} \times \int I \times dt \quad (10)$$

where

U_{ps} is the protection level at switching current impulse (EN 50526-1);

I is the current through the arrester as a function of the time.

6.6.2 Typical overvoltages during clearing a line fault

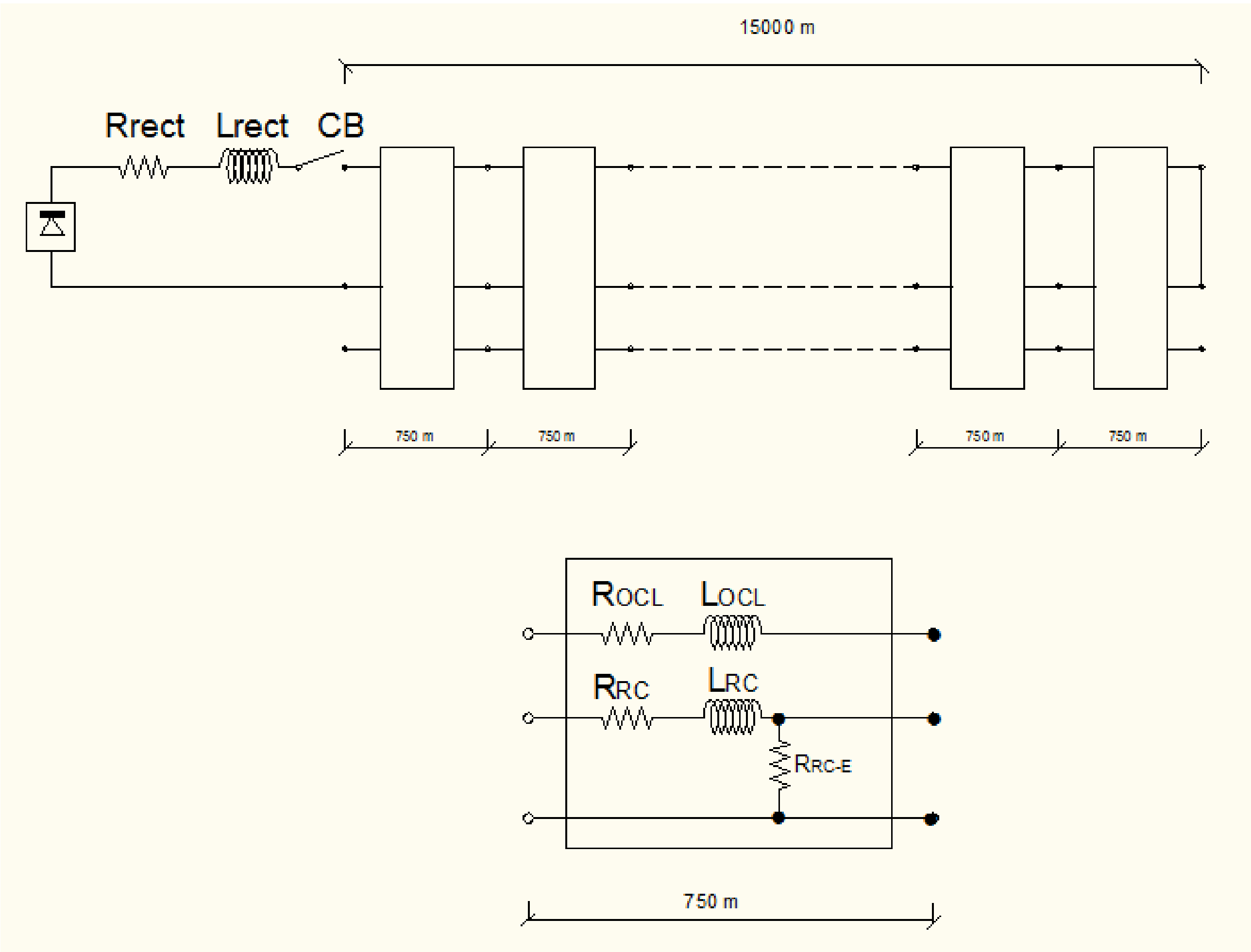
The amplitude and the duration of the overvoltage during opening of circuit-breakers, cutting a short-circuit, are different for the A1 and A2 arresters, and they depend on many parameters: voltage of the network, voltage prior to the fault in the fault location, distance to the substation, the peak current, time constant, type and technology of the circuit-breaker, presence of filters after the rectifier, insulation of the track, use of voltage limiting devices.

For the d.c. 750 V systems the margin between the value U_c indicated in Table 4 and the nominal voltage is such that no appreciable current will flow through the arrester A2 during the line faults.

A different situation occurs in the d.c. 1 500 V and d.c. 3 000 V systems. In these cases it is not possible to give general indications on the voltages that appear on the track and on the OCL during the clearing process of a fault current. The following paragraphs give an example of how to calculate the voltage to earth of the catenary and of the track, as well as the shapes of the overvoltages.

Details on the simulation are indicated below.

Figure 6 shows the equivalent circuit of a 15 km line used in the simulations. The line is energized at the sending end from a substation. At the end of the line a short circuit to the track is present. The line equivalent circuit is made by cascading 20 sections, each equivalent to 750 m of line. The resistance (R_{OCL}) and the inductance (L_{OCL}) of the OCL, of the Return Circuit (R_{RC} ,L_{RC}) are represented as well as the Leakage Resistance to Earth of the Return Circuit ($R_{RC\text{-}E}$) calculated on the basis of the line constants per length (see Table 8). Fifteen km of line have been represented by cascading 20 of such equivalent circuits. No Arrester A1 nor VLD are installed along the line. The equivalent resistance and inductance of the rectifier (R_{RECT}, L_{RECT}) have also been included in the simulations. The circuit breaker closes on a permanent fault at 20 ms (t_1), trips when current reaches 2 500 A (at t_2=52 ms) and clears the fault at t_3=70 ms. The circuit breaker, CB, has been represented as a time varying resistance, variable according to the values reported in Table 6, obtained by assuming the following empirical formula R=0,0125 x $(t-t_2)^3$ for the arc resistance.



Key

OCL Overhead Contact Line;
RC Return Circuit;
E Earth.

Figure 6 - Equivalent circuit used for the simulation of the transient voltages at clearing of a OCL-RC fault

NOTE The equivalent circuit shown in Figure 6 is able to represent with sufficient accuracy the overvoltages associated with the clearing process of the circuit breaker, able to affect the operation of the surge arresters. It is not able to represent the transients associated with the arc quenching process in the last stage of the interruption, when the current is reduced to very low values such that the arc becomes unstable and is suddenly quenched. These transients are not of such an amplitude as to affect the arrester operation and are out of the scope of the calculations dealt with. The formula applied to represent the circuit breaker has proved to be appropriate for the calculations under consideration. It cannot be used for calculation of the arc behaviour inside the arc chute.

Table 6 – Values of circuit breaker resistances as a function of time

T **ms**	**Circuit breaker resistance** **Ω**
$0<t<t_1$	∞
$t1<t<t_2$	0
$t>t_2$	$0,0125\ (t-t_2)^3$

Table 7– Constants of the line represented for each 750 m section

Resistance Ω	Inductance mH
R_{OCL}=0,0375	L_{OCL}=1,05
R_{RC}=0,0075	L_{RC} =0,3
R_{RC-E}=2,67	-
R_{RECT}=0,05	L_{RECT}=0,3

Table 8 – Constants of the line represented per length of line

	Resistance Ω/km	Inductance mH/km	Leakage resistance to earth Ω km
OCL	0,05	1,40	
RC	0,01	0,40	
RC-E		-	2,00

The operation results in an overvoltage on the d.c. 3 000 V busbar in the substation, and in an overvoltage on the track near the short-circuit and on the return circuit in the substation.

Figure 7 represents all the parameters that are given in Figures 8 to 13.

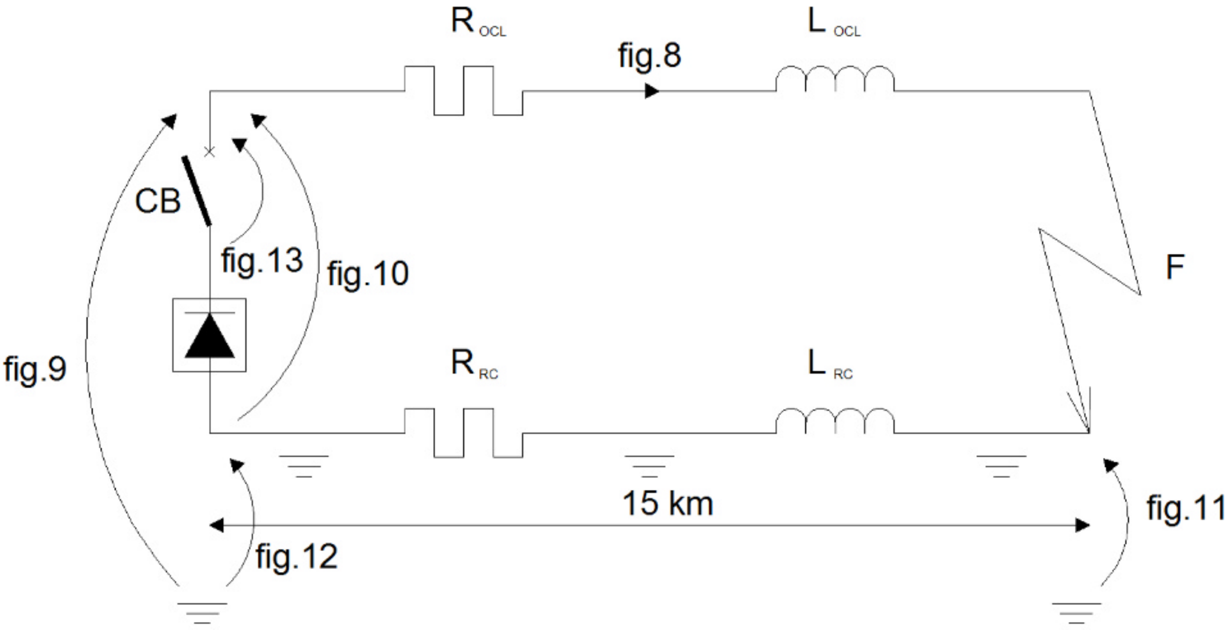
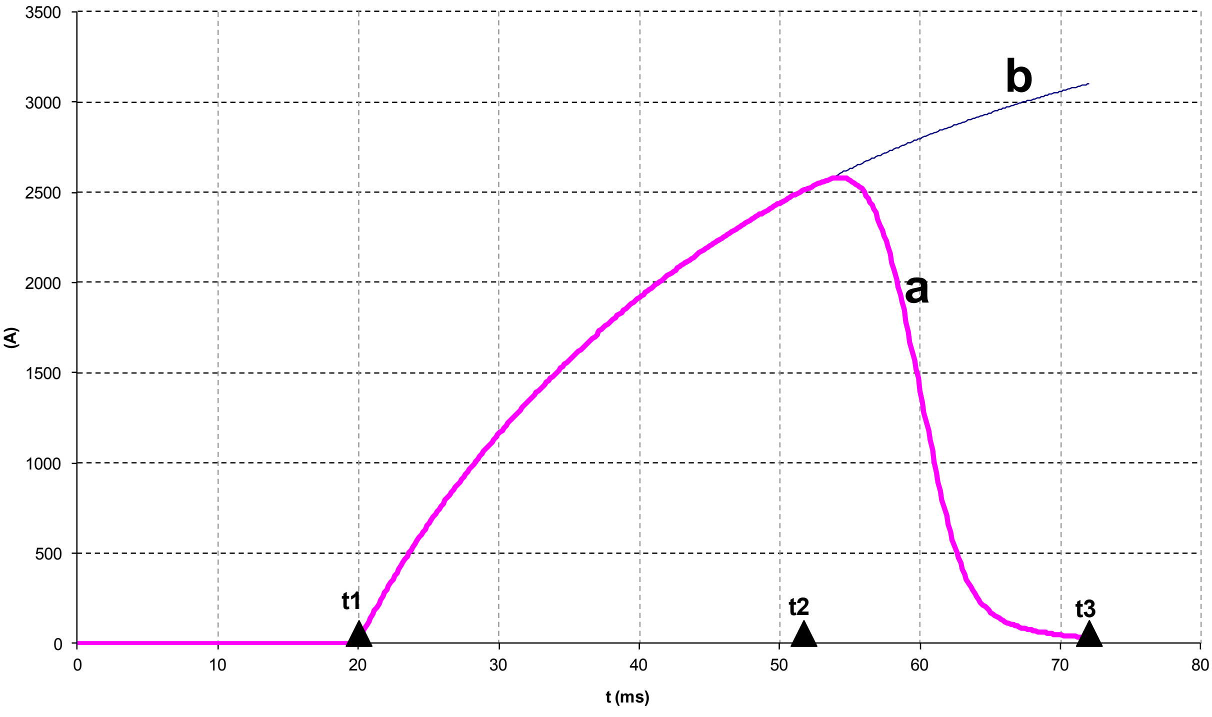


Figure 7 – Energization of a d.c.3 000 V faulty line – Equivalent circuit



Key

a curves with opening of the circuit breaker
b curves without opening of the circuit breaker
t1 20ms = fault inception
t2 52ms = circuit breaker begins to open at 2500A
t3 about 70ms = fault is cleared at about 70ms

Figure 8 – Short circuit current I as a function of time. The fault inception is at 20 ms, the circuit breaker begins to open approximately at 52 ms, when the current is approximately 2 500 A, the fault is cleared at about 70 ms

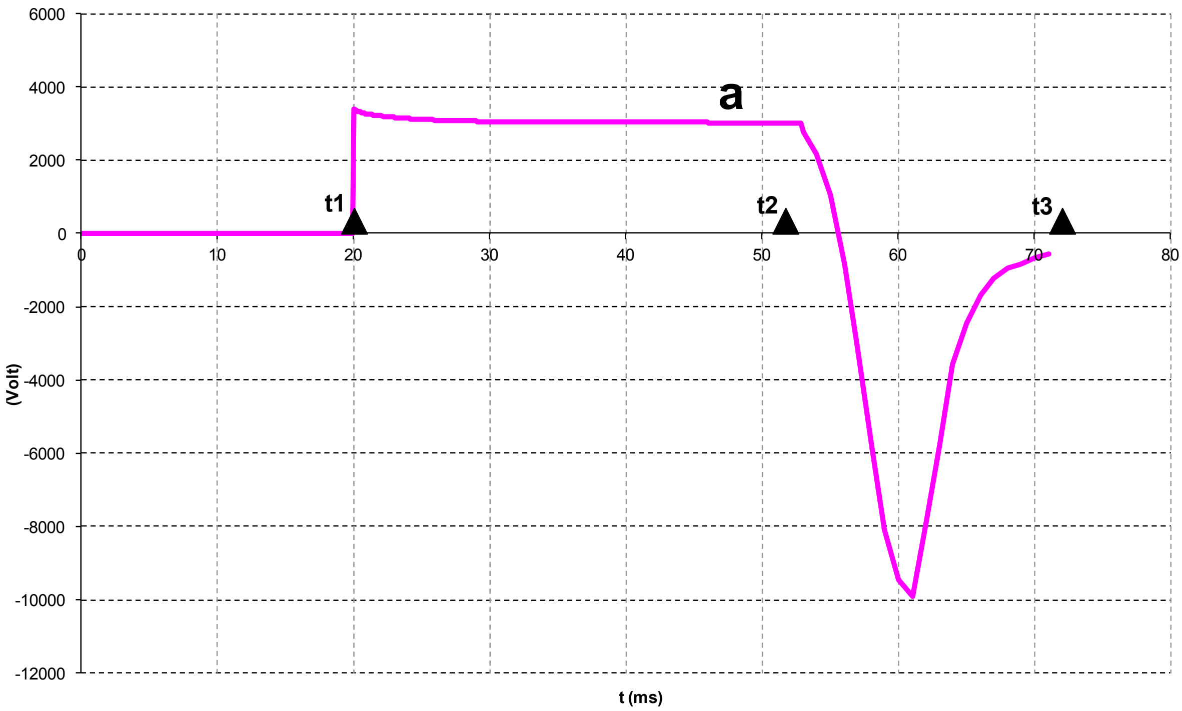


Figure 9 – Voltage to earth of the line sending end as a function of time

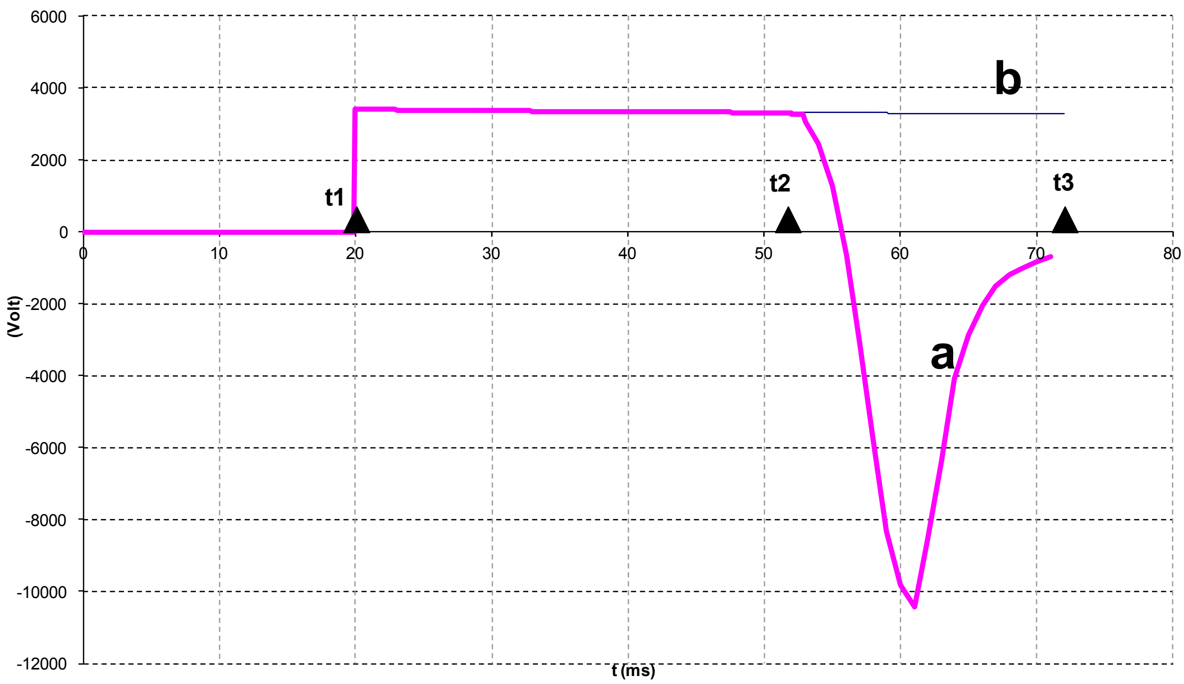


Figure 10 – Voltage of line sending end to the negative busbar as a function of time

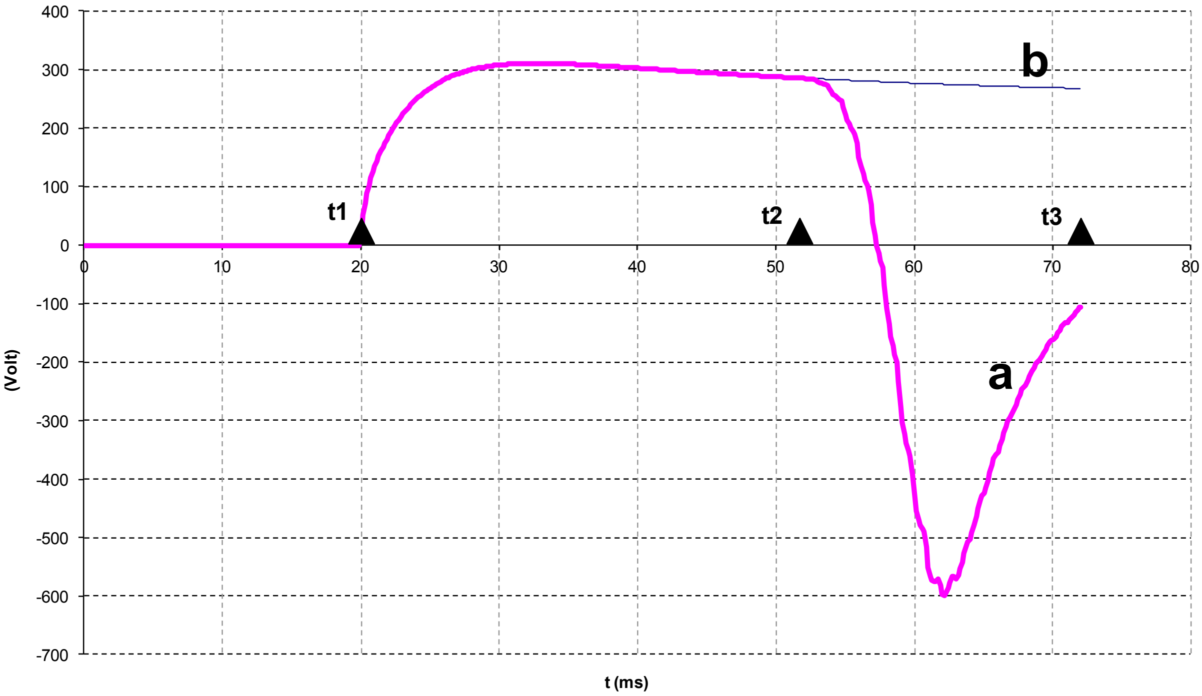


Figure 11 – Voltage of the track to the earth at the place of the short circuit as a function of time

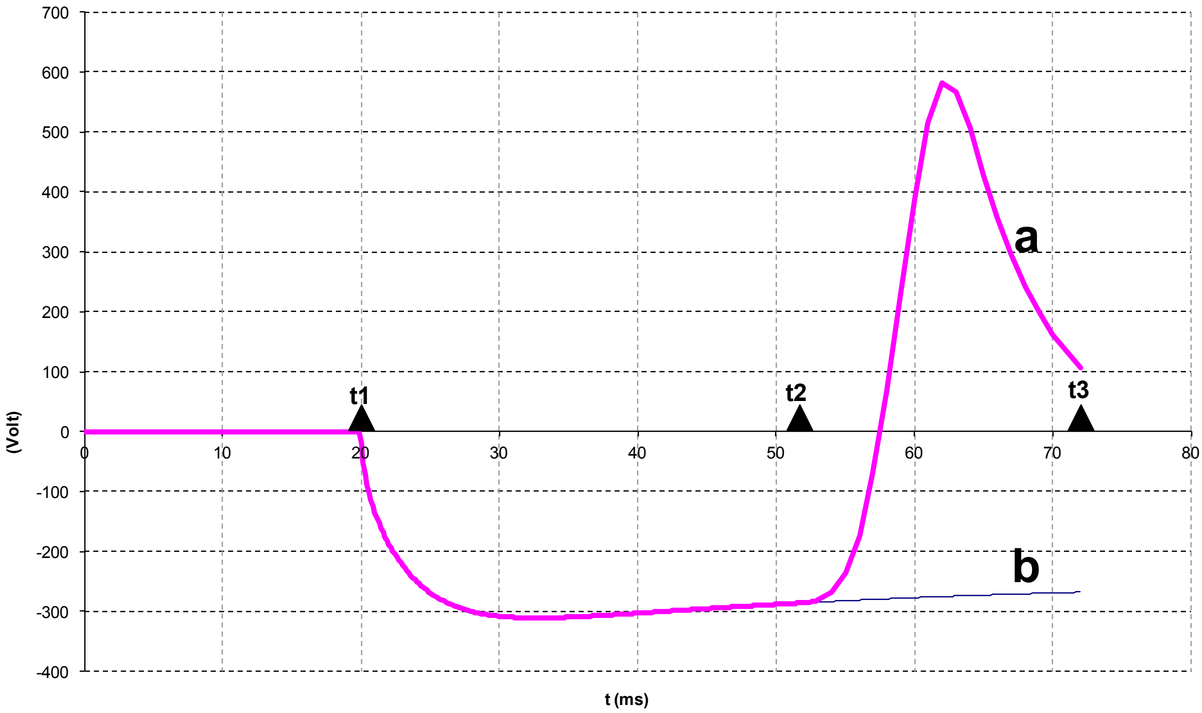


Figure 12 – Voltage to earth of the negative busbar in the substation as a function of time

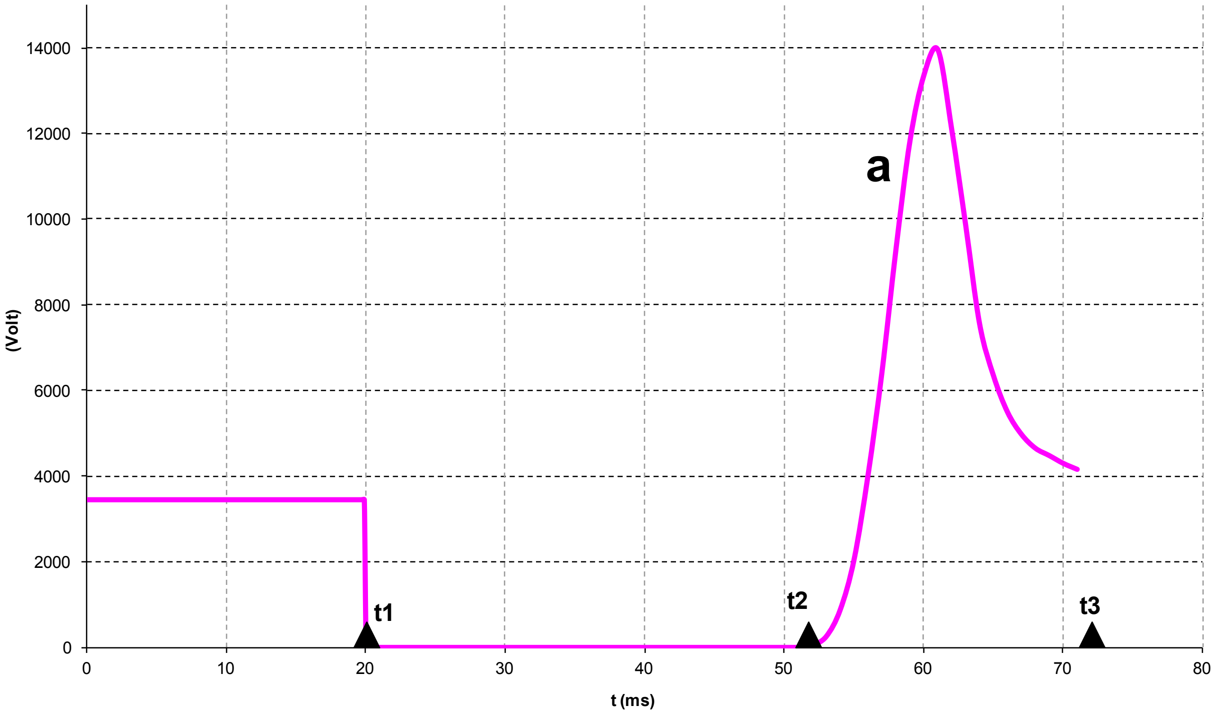


Figure 13 – Voltage across the contacts of the circuit breaker as a function of time

6.6.3 Arrester A1

As far as the energy (charge transfer) capability is concerned two different procedures may be followed for the choice of the arresters A1 (see Figure 14).

Method A

If the arrester chosen has a minimum switching impulse protection level U_{ps} greater than the maximum switching overvoltage level of the system at the site of the arrester installation the arrester will take no or negligible energy during switching, because of no charge transfer.

Method B

If the arrester chosen has a minimum switching impulse protection level U_{ps} lower than the maximum switching overvoltage level of the system at the site of the arrester installation care shall be given to the energy that is dissipated in the arrester because of the switching overvoltages, in particular during the opening of the circuit breakers.

In this case, a calculation should be done of the energy and charge transfer in the worst case circumstances, to determine the required arrester characteristics. The lower U_{ps} is, the higher the charge transfer and energy will be.

NOTE

Method A:

This is the easiest method, because it does not require an energy and charge-transfer calculation during switching, only during lightning.

Only the amplitude of the real switching overvoltage has to be known, not the duration.

The protection level U_{pl} will be higher than in Method B.

Method B:

With respect to Method A, Method B results in lower U_c giving lower protection level U_{pl} and larger protected zone, but with increased charge transfer capability demand with the switching overvoltages.

Shape and duration of the actual switching overvoltages has to be known.

6.6.4 Arrester A2

Formula (3) applies also to the insulation coordination of arrester A2 and the protected equipment.

It is to be recommended that the switching protection level U_{ps} of this arrester is higher than the maximum switching voltage level. Figures 9 to 13 give an example of the switching overvoltages for systems rated at d.c. 3 000 V.

NOTE This condition is automatically complied with in the d.c. 750 V systems due to the low value of U_n and to the voltage drop along the contact line during the faults if U_c of A2 arresters is chosen according to Table 4.

A lower U_{ps} can be chosen, if switching overvoltages are lower than the maximum permissible effective touch voltages *U*te, max in Table 6 of EN 50122-1:2011, even in the worst circumstances (possibly in the d.c. 1 500 V systems). A2 arresters Class DC-B or DC-C seem appropriate for the substations. If the arresters A2 are installed along the lines to protect for instance the voltage limiting devices connecting the poles to the return circuit, a Class DC-C arrester may be recommended in case of high exposure to the lightning strikes.

6.7 Procedure to select an A1 arrester

In summary, for the selection of an arrester the following steps are required (see Figure 14):

1) On the base of the nominal voltage, U_n, find the value of U_{max2}

2) Define U_c of surge arrester ($U_c \geq U_{max2}$);

3) Choose the arrester Class[1].

4) Compare the value of the switching protection level of the arrester, U_{ps}, with the maximum switching overvoltage U_{SO}[2]; If $U_{ps} > U_{SO}$ go to step 11), otherwise go to step 5);

5) If Method A is chosen go to step 9) otherwise go to step 6);

6) Calculate the maximum energy dissipated (W_{max}) in the arrester when the maximum switching overvoltage is applied;

7) Is the Charge transfer capability of the arrester, Q_T, multiplied by the U_{ps}, higher than W_{max} ? If yes go to step 11) otherwise go to step 8);

8) If arrester Class is =DC-C go to step 9) otherwise go to step 10);

9) increase U_c and go to step 3);

10) increase the Class of the arrester and go to step 4);

11) Determine U_{pl} of the arrester;

12) Choose a value for the factor K dealt with in 6.5;

13) Calculate Minimum $U_{Ni} = K \cdot U_{pl}$;

14) System U_{Ni}[3] is greater than Minimum U_{Ni}? If yes the arrester selection is finished, otherwise go to step 15);

15) Reduce the value of U_c and go to step 3);

NOTE 1 An arrester Class DC-A can be chosen as a first step. On the base of the experience, taking into account the keraunic level of the area and the reliability requested, Class DC-B or DC-C could also be chosen in this step.

NOTE 2 The maximum switching overvoltage does not exceed four times the nominal voltage (as specified in EN 50123-2:2003, 5.7).

NOTE 3 U_{Ni} is specified in EN 50124-1 for the given nominal voltage.

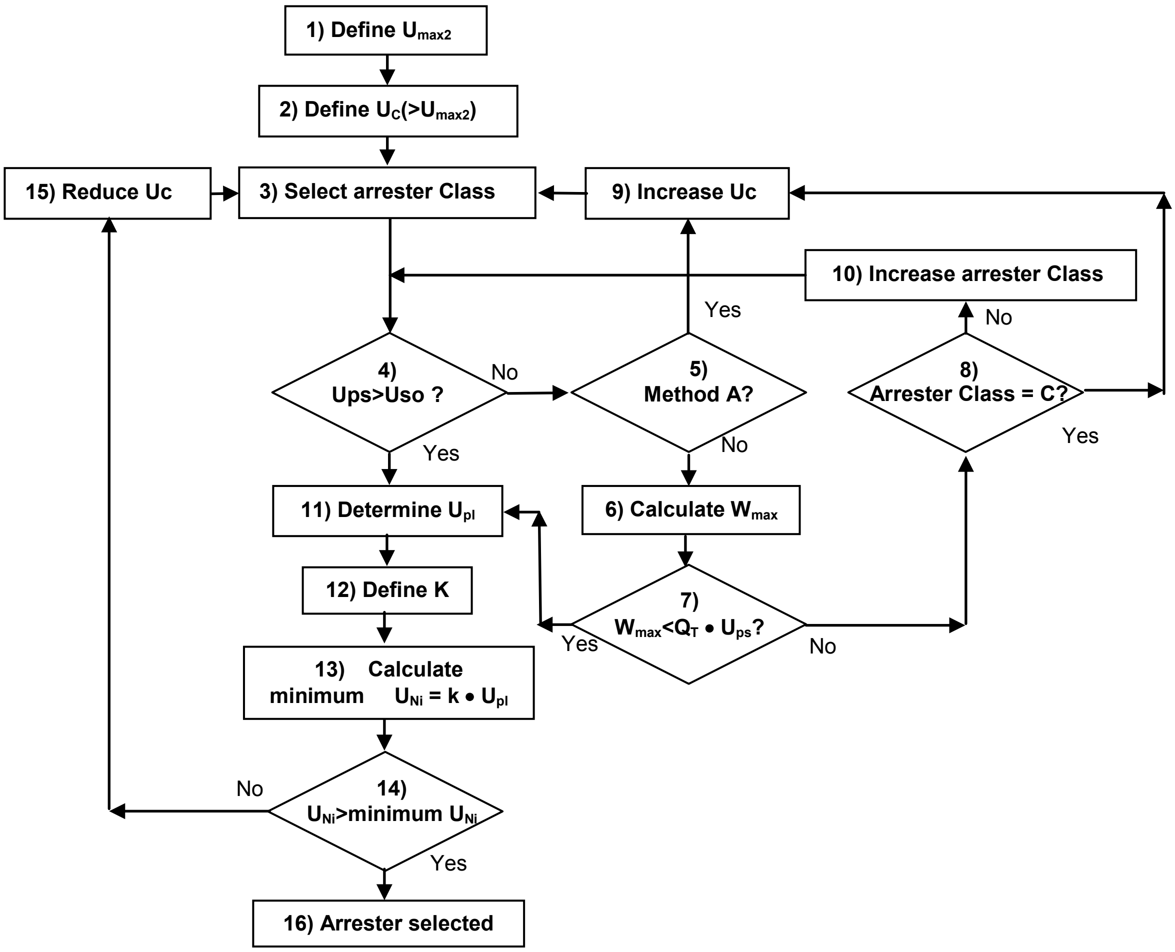
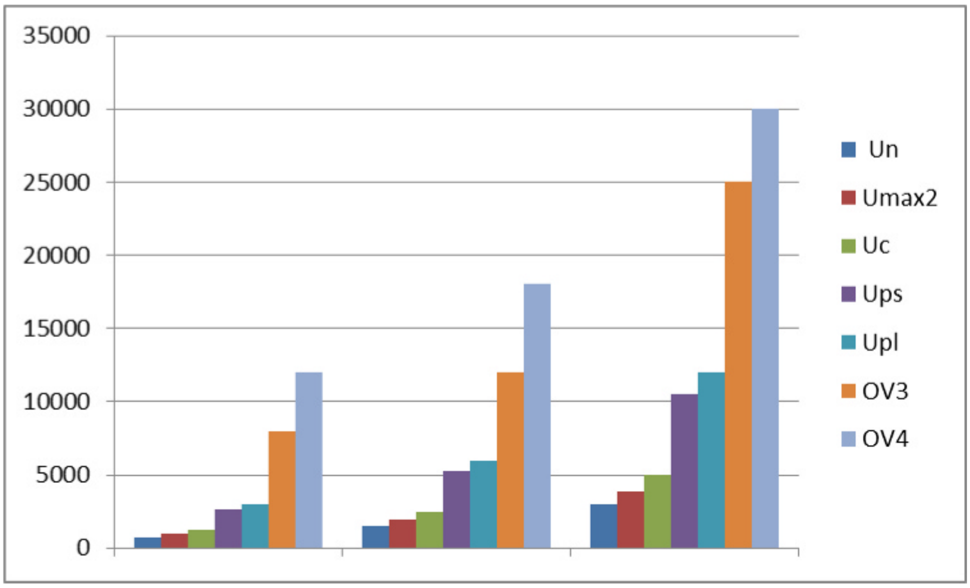


Figure 14 – flow chart for selection of arrester

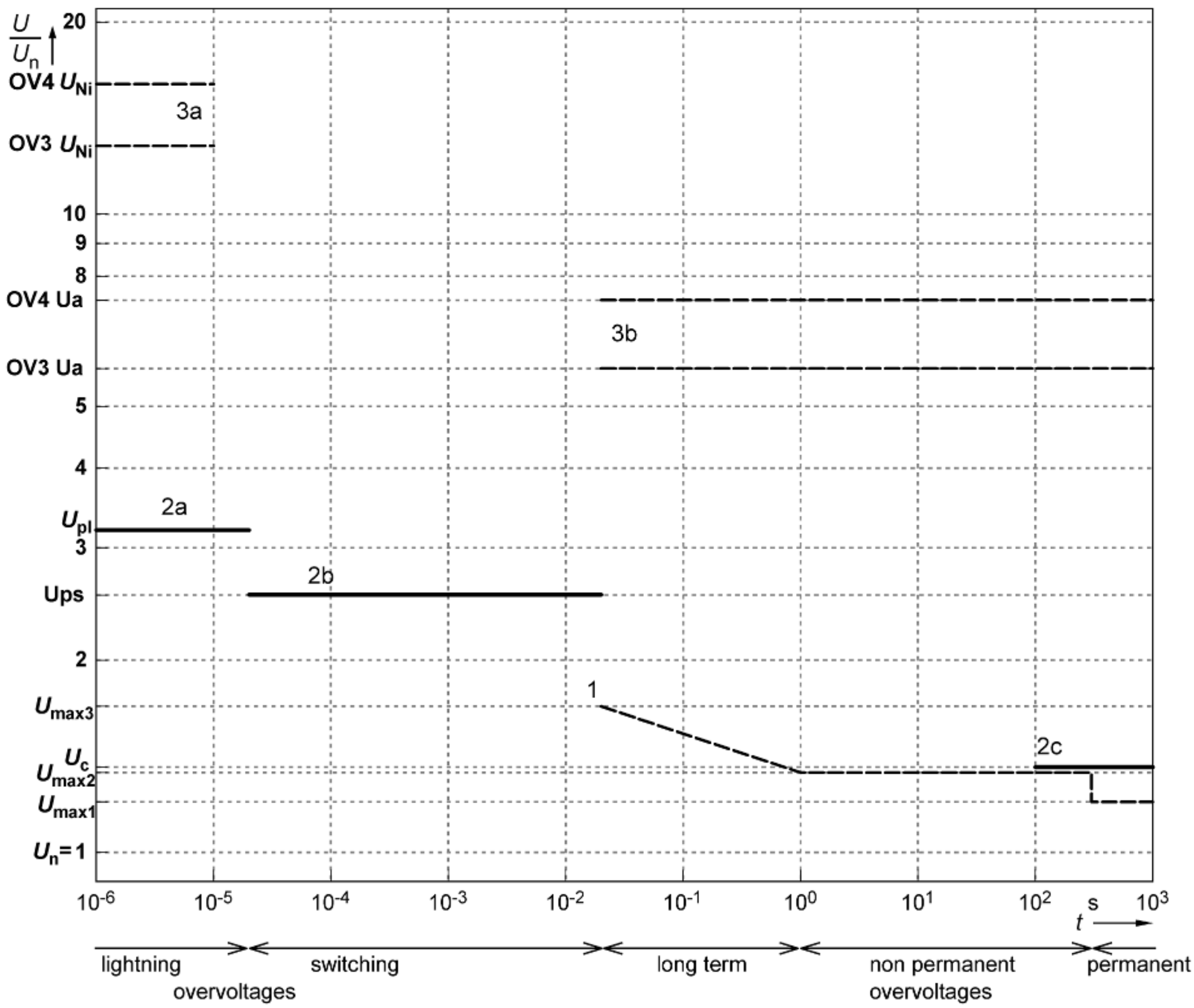
Figure 15 shows the application of method A for the choice of arrester A1 in systems with a nominal voltage of d.c. 750 V, d.c. 1 500 V or d.c. 3 000 V.

In Figure 15 the following assumptions have been made: Arrester Class = DC-B; maximum switching overvoltage U_{ps}= 3.5 × U_n, depending on the system it could be lower or higher; U_{ps} = 2,1 U_c; U_{pl}= 2,4 U_c. Manufacturing tolerances on U_{ps} and U_{pl} should be considered, they are in the range of -6 % to -10 % with respect to the data referred to in the arrester data sheet. As the arrester has some switching surge charge transfer capability, in practice values of Uc some 5-10% lower than the ones shown in the diagram may be applied and have proved to be appropriate. For Classes DC-A and DC-C refer to Table 1 for ratios U_{ps}/U_c and U_{pl}/U_c.



U_n	U_{max2}	U_c	U_{ps}	U_{pl}	OV3	OV4
750	1000	1250	2625	3000	8000	12000
1500	1950	2500	5250	6000	12000	18000
3000	3900	5000	10500	12000	25000	30000

Figure 15 – Surge arrester A1 for d.c. 750 V, d.c. 1 500 V and d.c. 3 000 V. (example of application of method A)



Key

1 supply voltages of traction system

U_n nominal system voltage according to EN 50163

U_{max1} highest permanent voltage according to EN 50163

U_{max2} highest non permanent voltage according to EN 50163

U_{max3} highest long term overvoltage according to EN 50163

2c continuous operating voltage U_C of the surge arrester

2a lightning impulse protection level U_{pl} of the surge arrester

2b switching impulse protection level U_{ps} of the surge arrester

3a lightning impulse withstand voltage of d.c. substation equipment U_{Ni}

3b power frequency withstand voltages (r.m.s. values are shown in the diagram) of d.c. substation equipment U_a

t duration

Figure 16 – Insulation coordination of the OCL and A1 surge arresters

Figure 16 shows a diagram giving the insulation coordination of the OCL or parts connected to it with an A1 arrester. The time scale is divided into the different ranges that are relevant for the occurring overvoltages and operational voltages. The ordinate indicates the respective voltage normalized to the nominal system voltage. The curves 3a and 3b show the withstand voltages of equipment depending on the overvoltage category. These voltages shall not be exceeded, i.e. the protection level of the arresters shall be clearly below these test voltages. Curve 1 shows the admissible system voltages, i.e. the voltages that may occur during normal and abnormal operation conditions. The arrester A1 shall withstand these voltages.

Curve 2 shows a typical A1 arrester behaviour, fulfilling the requirements for sufficient protection but not interfering with the operational voltages.

6.8 Procedure to select an A2 arrester

The recommended minimum values of U_c are indicated in Table 4. System studies are necessary to calculate the proper value of the charge transfer capability. For A2 arresters connected to the poles supporting the OCL in open air, it is recommended to consider the direct lightning current impulse withstand test to determine the energy and the surge arrester Class together with the charge transfer during switching in method B.

6.9 Connecting leads of arresters

The leads that connect to the protected equipment the live terminal of the arrester and the earth terminal are affected by some inherent inductance. When the arrester is discharging the lightning overvoltage, these inductances cause voltage drops that will add to the residual voltage of the arrester thus reducing the protective effect. The inductance per length of a lead is a complex function of the lead geometry. The effect of the lead conductor diameter is relatively small. Tests indicate that an inductance in the range of 1 µH/m to 1,3 µH/m is typical. The inductance per length of conductor which has bends or loops will be much greater than this value.

For the above reasons lead lengths should be kept as short as practicable with no kinks or bends.

6.10 Earthing requirements

The effect of the resistance of the earth electrode to which the earth terminal of the arrester is connected deserves some special consideration.

a) The impulse resistance of the earth electrode increases the voltage to earth at the live terminal of the arrester. This impulse resistance is lower than the power frequency resistance. A formula giving the impulse footing resistance of a pole struck by the lightning is:

$$R_i = R_0/\sqrt{(1+I_R/I_g)} \quad (11)$$

where

$$I_g = E_g\ \rho/(2\pi\ R_0^2)\ (\text{kA}) \quad (12)$$

and

R_i = pole footing resistance when draining the lightning current I_R (Ω)

R_0 = power frequency pole footing resistance (Ω)

E_g = soil breakdown gradient assumed equal to 300 kV/m

ρ = soil resistivity (Ωm)

I_R = peak strike current drained (kA)

Figure 17 shows the relationship between R_i and R_0 for the case of ρ=1 000 Ωm, I_R=10 kA.

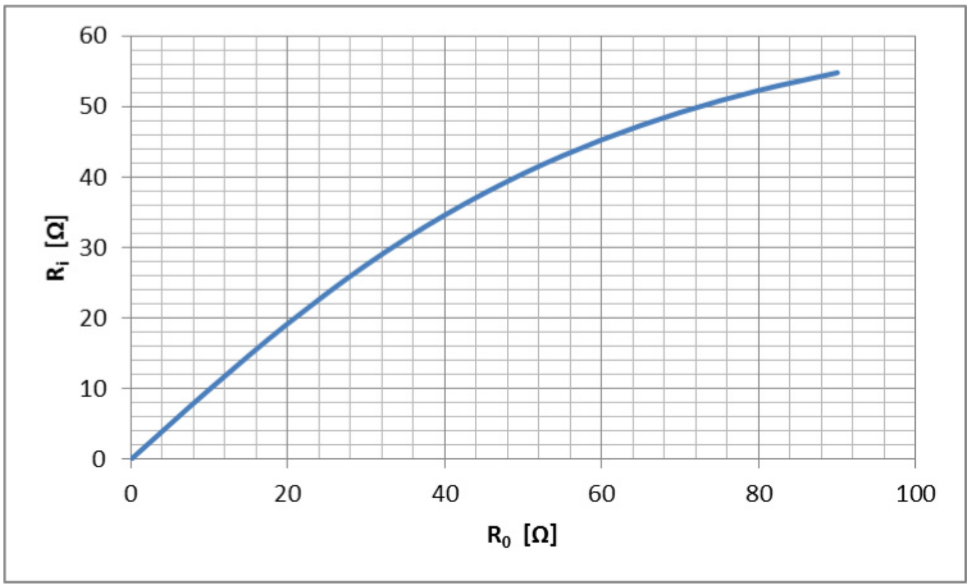


Figure 17 – Lightning impulse pole footing resistance as a function of the power frequency resistance

b) The earthing grid of a substation has usually an R_0 < 2 Ω. Along the lines, the pole footing resistance is in general higher. Experience shows that lightning behavior is satisfactory if R_0 < 10 Ω, but this value may be difficult to attain especially in rocky areas. For safety reasons the poles may be connected together by an earthing wire, but this fact has a reduced effect when a lightning overvoltage is drained because of the length of the earth wires connecting the poles and the steepness of the front of the overvoltages.

c) As already mentioned, the best protection of the positive-to-earth insulation of an equipment is obtained by reducing as far as possible the length of the connecting leads of the arrester and connecting the earth terminal of the arrester to the same earth of the protected equipment. In this case the earthing resistance has no influence on the protective behavior of the arrester as the voltage drop in the earthing resistance when draining the discharge current is external to the arrester-insulation loop circuit and does not affect the voltage stressing the insulation protected. The use of the metallic pole as down conductor is a preferred solution to reduce inductive effect compared to cables.

d) Connecting the earth terminal of the arrester to an earthing system independent from the earthing system of the equipment to be protected, where applicable, causes reduced protective behavior and cannot be recommended.

7 Guideline for VLDs

7.1 Introduction

During normal operation, due to the voltage drops along the return circuit caused by the currents absorbed by the train traffic, or in conjunction with fault condition such as insulation failure or OCL fall, impermissible voltages could appear across accessible points of the return circuit and earth or an earthed structure such as a OCL pole or an earthed frame in the OCLZ or in the CCZ. In order to limit these voltages below the safe values as defined in EN 50122-1:2011, 9.3.2.2 and 9.3.2.3, VLDs with proper ratings may be applied as indicated in the following.

VLD-O devices may be applied in the case of normal operation, i.e. when the excessive voltage is caused by train operation, VLD-F in fault condition. According to the characteristics, VLD-O devices may also perform the F function.

Because of the differences existing between the d.c. 750 V system and the d.c. 1 500 V – d.c. 3 000 V systems this Application Guide deals with these two subjects separately.

7.2 General

As already mentioned in Clause 4, VLDs are applied in order to protect persons against impermissible touch voltages. It is to be differentiated between the following situations:

- normal operation;
- fault condition.

It is not a functionality of VLDs to protect anything against lightning and switching overvoltages. This protection should be provided by surge arresters (see Clause 4).

The following subclauses describe the application of VLDs in the area of mass transit railways and trams with nominal voltage up to d.c. 750 V (7.3) as well as main-line railways with nominal voltages of 1 500 V or 3 000 V (7.4).

According to EN 50122-1:2011, 3.4.7 and 3.4.8 the systems up to, and included, 1 500 V d.c. are low voltage systems. 3 000 V d.c. system is a high voltage system.

In the low voltage systems with double or reinforced insulation of the contact line, the supporting structures including masts for OCL systems need not be earthed and need not be connected to the return circuit (see 6.2.3.2 of EN 50122-1:2011). For such exposed conductive parts VLDs are not necessary.

If the poles are not connected together by an earthing wire and the OCL system does not have double or reinforced insulation it is in general necessary to install a VLD at every pole unless the poles are directly bonded to the rails and insulated from earth.

7.3 Mass transit railways and trams (U_n up to d.c. 750 V)

7.3.1 General

In Europe, there are mainly three kinds of mass transit railways:

– trams with OCLs (mainly above-ground, train length up to 75 m);
– metros with a conductor rail (mainly underground, train length up to 120 m);
– light rail metros with OCL (partly above-ground, partly underground, train length up to 120 m).

Special kinds of mass transit systems, not included in the above list, may be treated according to their particular characteristics.

7.3.2 Trams with OCL

In normal operation rail potentials up to 90 V can occur; therefore the protection of persons against impermissible touch voltages is normally not necessary. In general, no VLD-O is necessary.

The application of VLDs is required in cases where exposed electrically conductive parts (e. g. waiting rooms, fences, grids or banisters) are within the OCLZ, which cannot be permanently connected to the rails (return circuit) because of their connection to other potentials (e. g. earth). In the case of line fault these exposed conductive parts could take a dangerous voltage from the OCL.

To protect persons against electric shock by touching these exposed conductive parts in a fault condition, the “open connection to return circuit” is necessary, that means the connection to the return circuit via a VLD-F.

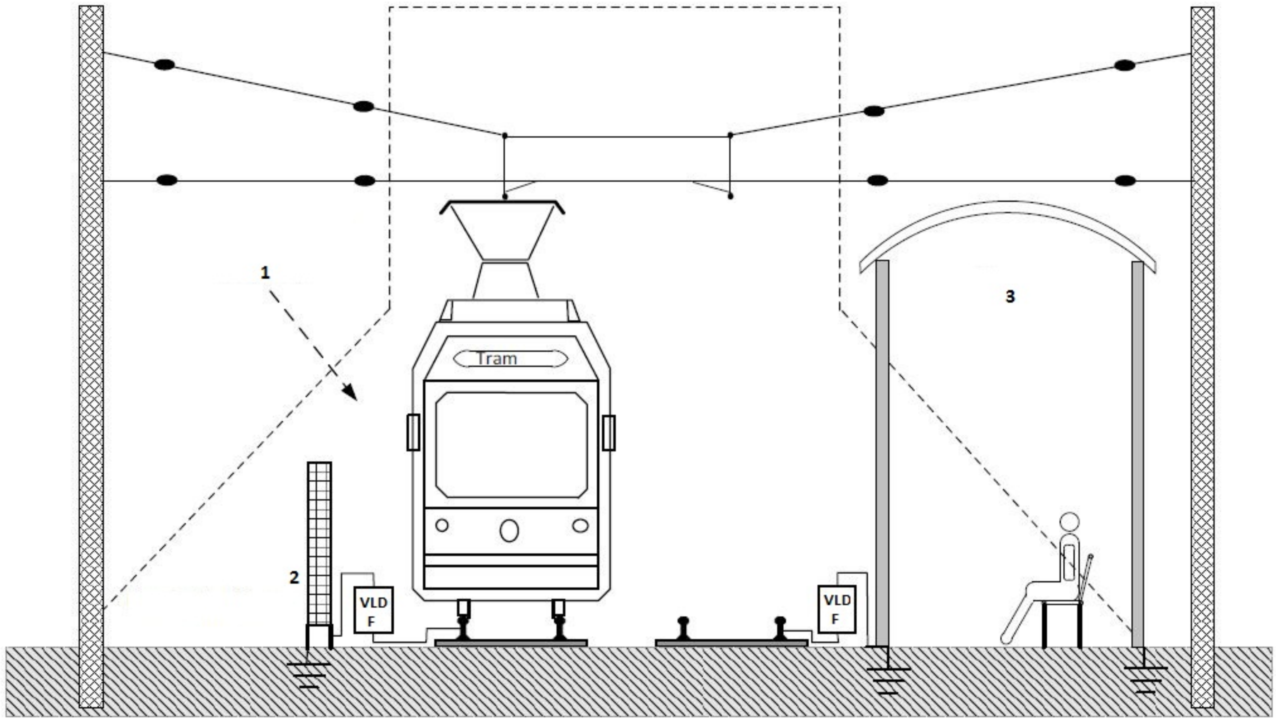
Following the contact of one of these exposed conductive parts with a broken OCL, the operation of the VLD-F causes a short-circuit of the power supply immediately followed by triggering of the short-circuit protection and thus by switching-off the supply voltage.

If a VLD-F is applied, which cannot recover after a fault current, special means should be taken to inform the operating staff about the triggering in order to initiate corrective measures and to avoid the spread of stray-currents. This may be done by technical solutions (a message is sent if the current through the VLD rises above a certain value or the voltage across the VLD is permanently zero) or by organisational means which ensure the early replacement of a VLD that has triggered (e. g. periodical inspection).

In order to avoid triggering by atmospheric influences (lightning strikes) the triggering voltage should be chosen to an adequate value. Practical experiences have shown that VLDs with a nominal triggering voltage U_{Tn} = 300 V lead to a negligible number of triggerings caused by lightning strikes in the near surroundings. According to EN 50122-1:2011 (Table 6) the maximum duration for a voltage up to 300 V to be allowed is 0,7 s; therefore it is necessary that the VLD triggers within a time less than 0,7 s.

If lightning-resistant VLD-F are applied, a nominal triggering voltage U_{Tn} = 120 V is adequate.

Figure 18 gives an example on the use of VLD-Fs in the OCLZ of tramways. The layout of the OCL in the figure is only indicative.



Key

1 OCLZ / CCZ

2 conductive fence

3 waiting room

Figure 18 – Example for the application of VLD-F at exposed conductive parts in tramways within the OCLZ

7.3.3 Metros with a conductor rail

Because no break has to be considered of conductor rails (EN 50122-1:2011, 4.2) there is no OCLZ and CCZ, if not otherwise specified by the infrastructure manager, within which exposed conductive parts shall be protected against impermissible touch voltages.

Impermissible touch voltages can occur if, according to special operational situations, the rail potential in relation to the structure earth, earth or a platform arises to impermissibly high values. Also in a fault condition, the associated high rail potential should be considered. Because the body of trains or other rail vehicles have the rail potential, danger may occur to passengers or staff personnel. Also if work is done in the area of the track danger may occur to the service personnel, if the rail potential is too high. The danger may comprise electric shock or flashing arc, if the rails are connected to an earthed equipment.

Rail potential above 120 V (in relation to structure earth) may occur several times in a day. The duration may be within a few up to 30 seconds. Therefore the application of Class 1 VLDs - such as are used in above-ground tramways - is not reasonable. Instead VLDs have to be used that re-open after a specified time and thus separate the rail potential from the structure earth to avoid the unacceptable spread of stray-currents. Therefore the application of VLDs Class 3 or 4 should be considered. Class 2 VLDs may be applied if the current which flows in them will pass through zero within an acceptable time from triggering, and thereby will restore their non-conducting state.

NOTE In d.c. systems the time to pass through zero of the current flowing in the VLD is not predictable.

The optimal protection of passengers against impermissible touch voltages is ensured if the VLDs are applied in or near metro stations.

Because of the high traction currents of metros these VLDs need an adequate breaking capacity in order to be able to securely disconnect the occurring high earth currents. At metros these earth currents may arise up to 1 500 A.

By choosing adequate VLDs the following criteria should be considered:

– the method of triggering (fixed value of the triggering voltage or the curve according to EN 50122-1)

– expected earth current

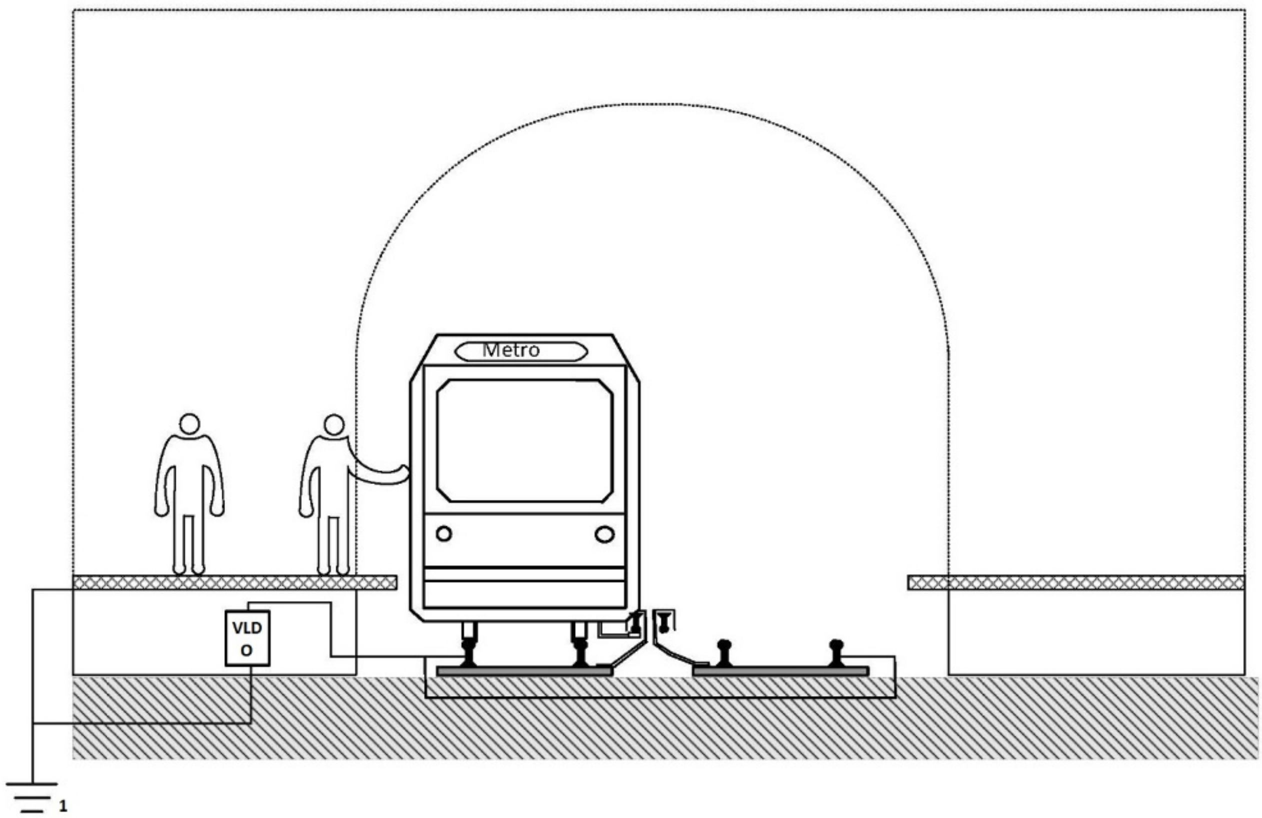
– breaking capacity

– blocking or alarm characteristic (if several triggering occur within a specified time)

– method of messaging the status (being blocked or closed during a long time or not)

The triggering characteristics of VLD and of the frame fault protection (with sensitivity to the voltage rail to earth) in the substation (EN 50123-7-1:2003, 6.5.7) should be coordinated to ensure that at first the VLD triggers in the case of high rail potential. Thus, unintended interruptions of the power-supply for the traction current can be avoided.

Figure 19 gives an example on the use if VLD-Os in metro systems.



Key

1 structure earth

Figure 19 – VLD-O to protect persons against high touch voltages at metros in normal operation

7.3.4 Light-rail metros with OCLs

Light-rail metros have some characteristics of trams (especially at operation above ground) as well as of metros (in tunnels and independent track constructions). Protective means should therefore be taken against danger for persons in the case of the break of the OCL (similar to trams). Because of longer and heavier trains light rail metros need higher traction currents than trams; therefore protective measures against impermissible touch voltages are applicable as for heavy-rail metros.

7.4 Railways (d.c. 1 500V … d.c. 3 000 V)

7.4.1 General

Due to the different safety requirements, the guide of application of VLDs along the lines or at the substations will be presented separately from the guidance for workshops or similar locations.

7.4.2 Application of VLDs along the lines or at the substations and in the sectioning posts

7.4.2.1 General

VLDs have to be connected across the return circuit and the accessible metallic exposed part whose voltage difference tends to exceed the permissible values. A metal oxide arrester A2 coordinated with the insulation level of the VLD should be connected in parallel if not integrated into the VLD.

According to the necessity unidirectional or bi-directional VLDs may be applied.

Application of Class 1 VLDs requires special provisions for remote status indication because the VLDs can become permanently closed. In general VLDs able to re-open after a specified time after triggering should be applied. Therefore along the lines, where no auxiliary power supply is in general available, only Class 2 VLDs are applicable. Class 2 VLDs give best performance against the effects of stray current if, after a certain time after triggering, the current in a VLD will cross through zero enabling the thyristors to become non conductive. On the contrary, in the substations and the sectioning posts Class 3 and Class 4 VLDs may be applied.

In choosing the characteristics of the VLD the expected long term current following the triggering of the VLD has to be evaluated in the most harmful situations (high traffic, high rail leakage resistance due to dry weather conditions). For the case of Class 3 and Class 4 VLDs, reopening of the VLD shall not occur if the current through the VLD is higher than the breaking capacity. See EN 50526-2:2014, 5.4.3. This breaking capacity should be higher than the expected long term current in the most hazardous situation (high traffic, combined with the high rail leakage resistance which occurs in dry weather).

In order to have recoverable VLDs, the minimum short-circuit current withstand should be higher than the possible short-circuit current/ time characteristic in the section of VLD installation.

NOTE It can be accepted that in case of severe short circuits the contacts of the contactors in the VLDs, Class 3 and 4, remain closed and have to be replaced.

Parallel VLDs at one place, in order to increase the short-circuit current withstand capability can only be accepted if simultaneous triggering can be guaranteed.

7.4.2.2 Application of VLD-Os

The application of VLD-Os is required if the rail potential along the lines, in the substations or in the sectioning posts, in normal operation, exceeds the values specified in Table 6 of EN 50122-1:2011, 9.3.2.2, for times greater than 0,7 s. A long term triggering voltage U_{LT} = 120 V may be suitable value. Class 3 or 4 devices are required.

If rail potential during normal operation would be high too frequently, for instance during each passage of a train, and consequently a too frequent triggering of a VLD-O would occur, an alternative solution to consider is the reduction of the distance between successive substations. A long-term triggering voltage U_{LT} > 120 V should not be accepted unless analysis shows that the risks associated with the higher U_{LT} will be tolerable. Such risk analysis should take into account the relevant parameters including: resistance of the standing surfaces, time limits, possibility to touch the train, etc. (see 9.2.2.4 of EN 50122-1:2011).

It should be taken into account that a VLD-O (Class 4 and in some cases Class 3) may also perform a VLD-F function if an earth fault occurs. The characteristics of the VLD should be such as to enable the VLD to perform the protective function if necessary and not to become permanently open circuited by such an event.

The suggested main characteristics of the VLD for this case are indicated in Table 11.

7.4.2.3 Application of VLD-F

As far as the fault condition is concerned, different cases should be considered:

1. Fault from OCL (or positive busbar) to earth (for instance because of the failure of a line or a substation insulator)

2. Fault from OCL on to a cabinet or other metallic frames in the OCLZ or in the CCZ.

If in one or in more of the cases above the touch voltage exceeds the limits in EN 50122-1:2011, 9.3.2.2 a uni-directional or bi-directional VLD-F should be applied, according to the case.

For the case of a short circuit from the OCL to the rail it can occur that the VLD-F triggers. If the VLD-F is of a Class 1 type, this causes a continuous connection between the rail and earth. Maintenance operations should ensure that the VLD-F is changed as soon as possible (see 5.7 of EN 50526-2:2014).

VLDs in a substation

For a VLD-F to be applied in a substation or close to a substation the maximum short-circuit currents will occur in case of faults. Compared to the devices in the line, VLDs with an auxiliary power may be applied.

VLDs along the lines

a) Structures supporting the catenary

The structures supporting the catenary are earthed through an earthing protective circuit formed by the poles with their foundation in the ground (sometimes with additional earthing rods). To respect the permissible touch voltages on the supporting structures of the OCL, VLDs connecting such structures to the return circuit are needed with a maximum distance between successive VLDs as per Table 10. Lower distances may be necessary depending on traction power system characteristics.

Table 9 – Recommended maximum distances, x, in between two consecutive VLDs along the d.c. 1 500 V and d.c. 3 000 V lines

U_n kV	x km
1,5	8
3	3,5

b) Low voltage electrical equipment along the line

The low voltage electric equipment along an electrified line is for example the signalling installations, the power supply systems of these signalling installations, switch heaters etc.

In most cases, many exposed conductive parts of the signalling equipment are in the OCLZ or in the CCZ as defined in EN 50122-1:2011, 3.5.9, 3.5.10 and Clause 4. Consequently, these parts have to be protected against accidental contact with the OCL, by means of a VLD. In order to limit the number of VLDs, more parts in a certain zone (for example all the signals powered by the same cabinet) could be connected together by means of a local earthing wire. This local earthing wire is then connected to the return circuit via a VLD.

NOTE In some cases (for example a signal-mast at a long distance from a VLD), the part to be protected can be insulated from earth and connected directly to the return circuit.

In all the above cases the protective circuit breaker(s) will suddenly clear the fault. The total break time will take less than 50 ms. According to EN 50122-1:2011, 9.3.2.2, the permissible touch voltage for such a time is equal to 735 V. An acceptable instantaneous triggering voltage U_{Ti} for the VLD-F should take into account the increase of the voltage during the clearing time of the circuit breaker. A suitable value of U_{Ti} may be 300 to 350 V. A triggering voltage U_T versus time may be accepted if calculations, taking into account the clearing behaviour of the circuit breaker, or tests show that the resulting touch voltage complies with the values in Table 6 of EN 50122-1:2011.

When specifying a VLD-F it has to be specified also the values of U_{TN} and of U_W according to the system requirements.

7.4.3 Recommended characteristics of VLDs

Table 10 provides the recommended characteristics of VLDs.

Table 10 – Recommended characteristics of VLDs

	Outdoor/ Indoor	Uni/bi – directional	Auxiliary power	Recoverable	Internal Lightning protection	Class
VLDs along the lines	Outdoor	Uni-directional (for VLD-F only) Bi-directional	No	Yes	Yes	2
VLDs in the substations	Indoor	Bi-directional	Yes	Yes	Yes	3,4

7.5 Workshops

7.5.1 Application of VLD-O

For the case of the workshops or similar locations the reduced value of 60 V is to be considered for the normal operation (see EN 50122-1:2001, 9.3.2.3). A value of U_{Tn} = 60 V is thus suitable.

If the return circuit is not permanently earthed in these installations, the bonding of the return circuit to earth by means of a VLD may allow the touch voltage to comply with the limits above.

7.5.2 Application of VLD-F

For fault conditions, EN 50122-1:2001, Table 6 applies.

8 Further considerations

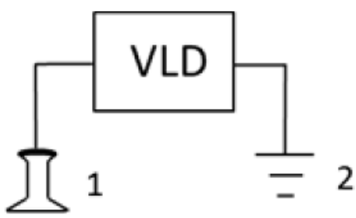
8.1 Installation recommendations

8.1.1 Mounting aspect

VLDs of Classes 1 and 2 are in most cases outdoor devices. These are mounted directly in open air or, if wished by the infrastructure manager, they could be mounted in a protecting cabinet.

VLDs of Classes 3 and 4 are in most cases indoor devices where the components are all mounted in a cabinet.

The earth terminal of the VLD is normally solidly connected to the enclosure as indicated in Fig. 20 and 21. In some cases, it may be necessary to isolate the earth terminal from the enclosure (see Fig. 22 and 23 for examples).

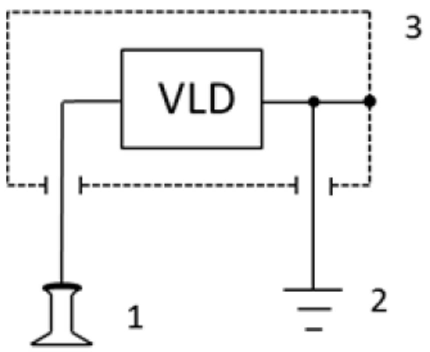


Key

1 return circuit

2 railway structure earth

Figure 20 – Normal bonding of a Class 1 and 2 VLD



Key:

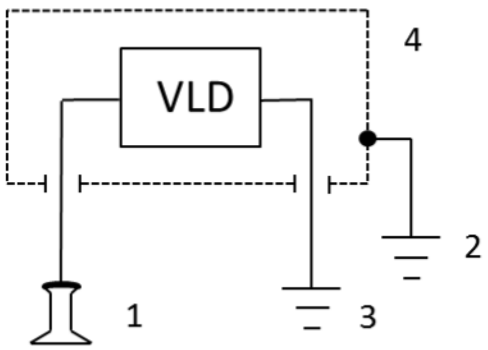
1 return circuit

2 railway structure earth

3 enclosure of the VLD

Figure 21 – Normal bonding of a Class 3 and 4 VLD

For indoor cabinets, it could be that the enclosure of the cabinet of the VLD is connected to another earthing system (e.g. earthing of the building in which the VLD is placed) than the earthed bar connected to the VLD (e.g. earthing wire along the railway, outside), as shown in Figure 22. In this case an insulation between the external earth bar and the enclosure of the VLD is required.



Key:

1 return circuit

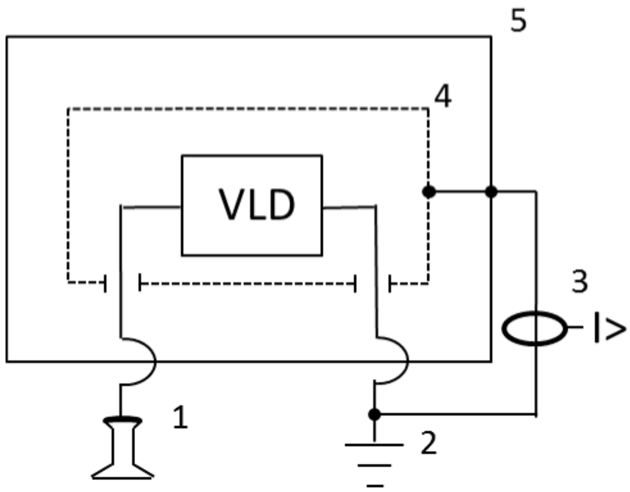
2 earthing of building in which the VLD is placed

3 railway structure earth

4 enclosure of the VLD

Figure 22 – Example of insulation of the terminals of a VLD from the enclosure

Another case is that the enclosure of the VLD is fixed to a panel that is provided with a frame fault protection. Insulating the earth terminal of the VLD from the cabinet avoids by-passing the frame fault protection. Otherwise, an unwanted frame fault trip will occur (see Figure 23).



Key:

1 return circuit

2 PE connection

3 earthing of the railway line, outside

4 enclosure of the VLD

5 enclosure of the panel

Figure 23 – Example of insulation of the terminals of a VLD from the enclosure and panel

8.1.2 Periodicity of inspection and management of alarms

8.1.2.1 General

It is recommended to keep a record of all the defects that are found and the repairs that are required and from time to time to review the periodicity of the inspections taking into account the information collected. The following paragraphs give an example of a plan that can be followed.

8.1.2.2 First installation of a VLD (of a defined Class) in the network

The behaviour of a VLD at one single place or more VLDs in a line, for a first time installed in the network, has to be followed (observed) during the first days and weeks, in order to check and to avoid a permanent unexpected closed VLD. Therefore, a remote status indication condition monitoring could be used.

For VLDs Class 3 and 4: The expected long term current, possible to flow through a closed VLD has to be measured in the most harmful situations (high traffic combined with the high rail leakage resistance which occurs in dry weather) and the breaking capacity of the chosen VLD should be adequate. A high breaking set current results in a lower total operation time of the VLD.

8.1.2.3 Periodic inspection

A recommended periodicity of inspection is one year for all Classes of VLD.

During this inspection, the parameters given in Table 11 should be verified.

Table 11 – Parameters to be verified in periodic inspections of VLDs

Class of VLD	Verification of …	According to subclause … of EN 50526-2:2014
All	the nominal triggering voltage U_{Tn} and the no-triggering voltage U_w	6.2
1, 2, 4	leakage current I_L	6.3
3, 4	Control functions	5.7

8.1.2.4 Devices with operation and alarm recordings

In case of alarms, the written procedures by the infrastructure manager have to be respected. It is strongly recommended that an intervention be planned as quick as possible so as to restore the required floating condition of the return circuit (see Annex F of EN 50122-1:2011).

8.1.2.5 Detailed review in case of major network or rail traffic modifications

Next cases require additional inspections of the VLD:

- significant traffic changes, for example in case of change of the places where trains often accelerate simultaneously;
- reduction of the resistance of the earthing system to which the earth pole of the VLD is connected, for instance in case of expansion of a railway station with a lot of new concrete steel reinforcements causing an increased current through the closed VLD.

8.1.3 Colours of the cables

The conductor to the return circuit should not be green/yellow.

The colour of the cable connected to the earth terminal of the VLD, if insulated, should be chosen according to the local practice.

8.2 Interaction between arresters and VLDs

If the VLD is not provided with an internal overvoltage protection an arrester A2 coordinated with the internal insulation of the VLD should be considered.

If the VLD is provided with an internal overvoltage protection and the charge transfer capability of the arrester inside the VLD is deemed insufficient, an A2 arrester matched with the arrester inside the VLD may be installed in parallel to the VLD.

8.3 Interaction with other systems

8.3.1 Interaction with signalling systems

VLD’s could be connected between the masts (poles, supporting structures of the OCL) and the return circuit.

Successive masts (poles) along an electrified railway are frequently connected all together with an earthing wire, grouping exposed metallic parts in the OCLZ or dewired CCZ. As the masts are high and in most cases in open air, they are likely to be struck by lightning.

These VLDs themselves should be protected by an A2 surge arresters, at least if it is required that they should be recoverable.

The U_c-value of the A2 surge arrester should be sufficiently high that the arrester will not be destroyed by the voltages on the return circuit. On the other hand, the U_c-value should be sufficiently low to allow the arrester perform an effective protection of the VLD. For recommended values of U_c see Table 4 "Recommended minimum values of U_c of A2 arresters"

The installation of the VLD in parallel with an A2 arrester (connected to the supporting structures of the OCL) has the disadvantage that the overvoltages on the supporting structures of the OCL (from lightning and the traction voltage itself during earth faults) are transferred to the return circuit. As the return circuit is connected to signalling equipment, these overvoltages are transferred to the signalling equipment. Therefore, this signalling equipment should be protected separately with surge arresters.

Provisions should be taken to avoid that, due to the installation of the VLD, lightning overvoltages higher than the insulation level of the circuits inside the cabinet may be transferred from the track and stress this insulation. The rated insulation voltage of these circuits, according to EN 50124-1:2001, 6.1.2.1, is 3,1 kV, but the experience shows that the overvoltages may be much higher.

8.3.2 Interaction with earthing systems

When applying VLDs in stations and depots, particular attention should be paid to the levels of the direct current which will flow in the earthing conductors and earthing systems when the VLD is in the conducting state. In particular, as electrical connections to non railway earthing systems are not desirable (see Clause 7 of EN 50122-1:2011), the possibility may be studied to separate the earthing system of the metal exposed parts in the OCLZ or CCZ (on and around the platforms in the stations), from the non railway earthing system. It avoids that the earthing conductors and earthing electrodes of these station installations could be endangered by currents from the return circuit or transfer dangerous voltages from the railway earthing system in the non railway earthing system.

8.3.3 Interaction with tunnel earthing systems

When applying VLDs in tunnels, particular attention should be paid to the levels of the direct current which will flow in the earthing conductors and earthing systems when the VLD is in the conducting state. Because of the very low earth resistance value of the structure earth of a tunnel, (very) high currents could flow. Attention should be paid that earthing conductors are not overheated by d.c. current. System studies will provide the solution for particular cases. The use of insulation Class II devices could be very helpful (no PE-conductor required).

8.3.4 Separation of a.c. cable screens

In d.c. traction power systems, the presence of a VLD may increase the possibility of adverse consequences of the connection of the metallic sheaths of the incoming a.c. power cables as described in EN 50122-1:2011, 7.1. Depending on local or national practice, the screen of the MV Cables is inside the substation either intentionally kept insulated or connected to the substation earth. If the screen is solidly earthed in both cable terminals, and the VLD is conducting, a closed circuit is formed by the railway return circuit, the VLD, the a.c power cable screen and the earthing system at the far end of the cable. This may cause overload of the screen of the cable, transfer impermissible voltages and overload the PE conductors of the consumers connected to the a.c. earthing system.

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