DD CLC/TS 50544:2010

BSI Standards Publication

Low voltage d.c. surge protective device for traction systems — Selection and application rules for surge arresters

National foreword

This Draft for Development is the UK implementation of CLC/TS 50544:2010.

The UK participation in its preparation was entrusted by Technical Committee PEL/37, Surge Arresters - High Voltage, to Subcommittee PEL/37/1, Surge Arresters - Low Voltage.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

ISBN 978 0 580 69171 3

ICS 29.120.50; 29.280

Compliance with a British Standard cannot confer immunity from legal obligations.

This Draft for Development was published under the authority of the Standards Policy and Strategy Committee on 30 April 2010.

Amendments issued since publication

Amd. No.	Date	Text affected

TECHNICAL SPECIFICATION
SPÉCIFICATION TECHNIQUE
TECHNISCHE SPEZIFIKATION

CLC/TS 50544

February 2010

ICS 29.120.50; 29.280

English version

Low voltage d.c. surge protective device for traction systems - Selection and application rules for surge arresters

Parafoudres basse tension courant continu pour traction - Principes de choix et d'application pour les parafoudres

Überspannungsschutzgeräte für Niederspannungs-Gleichstrom-Bahnsysteme - Auswahl und Anwendungsregeln für Überspannungsableiter

This Technical Specification was approved by CENELEC on 2009-12-25.

CENELEC members are required to announce the existence of this TS in the same way as for an EN and to make the TS available promptly at national level in an appropriate form. It is permissible to keep conflicting national standards in force.

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: Avenue Marnix 17, B - 1000 Brussels

Ref. No. CLC/TS 50544:2010 E

Foreword

This Technical Specification was prepared by the Technical Committee CENELEC TC 37A, Low voltage surge protective devices.

It also concerns the expertise of 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.

The broad subject of overvoltage protection in d.c. traction systems need to address the approaches, requirements and definitions of several disciplines and TC's. Concerned European Standards are referenced for generic definitions.

This Technical Specification reflects the common practise of overvoltage protection in the d.c. traction community, as far as protection of equipment in the primary power supply is concerned (e.g. feeders, overhead contact lines, return circuits, power side of rolling stock).

Therefore, definitions and approaches in this Technical Specification, covering a specific application in line with EN 50526-1, are different for some aspects from the definitions and approaches in the EN 61643 series.

The text of the draft was circulated for voting in accordance with the Internal Regulations, Part 2, Subclause 11.3.3.3. and was approved by CENELEC as CLC/TS 50544 on 2009-12-25.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN and CENELEC shall not be held responsible for identifying any or all such patent rights.

The following date is proposed:

– latest date by which the existence of the CLC/TS has to be announced at national level	(doa)	2010-06-25

This Technical Specification will be withdrawn once the SC 9XC document [1)] on the same subject is published.

[1)] Under development at the time of issue.

Contents

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1 Scope

This Technical Specification applies to non linear metal-oxide resistor type surge arresters (MO surge arresters) without spark gaps designed to limit voltage surges on d.c. traction systems with nominal voltage up to 1 500 V.

This Technical Specification applies to protection of equipment.

Same principles for selection and application apply for MO surge arresters on d.c. traction systems with nominal voltage 3 000 V.

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 50122-2	Railway applications – Fixed installations – Part 2: Protective provisions against the effects of stray currents caused by d.c. traction systems
EN 50124-1	Railway applications – Insulation coordination – Part 1: Basic requirements – Clearances and creepage distances for all electrical and electronic equipment
EN 50163	Railway applications – Supply voltages of traction systems
EN 50526-1 [1)]	Railway applications – Fixed installations – D.C. surge arresters and voltage limiting devices – Part 1: Surge arresters
EN 60071-1	Insulation co-ordination – Part 1: Definitions, principles and rules (IEC 60071-1)
EN 62305-3	Protection against lightning – Part 3: Physical damage to structures and life hazard (IEC 62305-3, mod.)

3 Terms and definitions

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

3.1 System voltages

3.1.1
nominal voltage
U_{n}
designated value for a system

[EN 50163]

3.1.2
highest permanent voltage
U_{max1}
maximum value of the voltage likely to be present indefinitely

[EN 50163]

1) At draft stage.

3.1.3
highest non permanent voltage
U_{max2}
maximum value of the voltage likely to be present as highest non permanent voltage for a limited period of time

[EN 50163]

3.1.4
highest long term overvoltage
U_{max3}
voltage defined as the highest value of the long-term overvoltage for t = 20 ms. This value is independent from frequency

[EN 50163]

3.1.5
rated insulation voltage
U_{Nm}
d.c. withstand voltage value assigned by the manufacturer to the equipment or part of it, characterizing the specified permanent (over five minutes) withstand capability of its insulation

[EN 50124-1, mod.]

3.1.6
rated impulse voltage
U_{Ni}
impulse voltage value assigned by the manufacturer to the equipment or a part of it, characterizing the specified withstand capability of its insulation against transient overvoltages

[EN 50124-1]

3.1.7
overvoltage
any voltage having a peak value exceeding the corresponding peak value (including recurrent overvoltages) of maximum steady-state voltage at normal operating conditions

[EN 50124-1]

3.1.8
long-term overvoltage
overvoltage higher than U_{max2} lasting typically more than 20 ms, due to low impedance phenomena e.g. a rise in substation primary voltage

[EN 50163]

3.1.9
transient overvoltage
short duration overvoltage of a few milliseconds or less due to current transfers

[EN 50124-1]

3.1.10
switching overvoltage
transient overvoltage at any point of the system due to specific switching operation or fault

[EN 50124-1]

3.1.11
lightning overvoltage
transient overvoltage at any point of the system due to a specific lightning discharge

[EN 50124-1]

3.2 Arrester

3.2.1
surge protective device
SPD
device that is intended to limit transient overvoltages and divert surge currents. It contains at least one nonlinear component

[EN 61643-11]

3.2.2
voltage limiting type SPD
SPD that has a high impedance when no surge is present, but will reduce it continuously with increased surge current and voltage. Common examples of components used as nonlinear devices are varistors and suppressor diodes. These SPDs are sometimes called “clamping type”

[EN 61643-11]

3.2.3
surge arrester
device intended to limit transient overvoltages to a specified level

NOTE Surge arrester, or shorter “arrester”, is a more general term for metal-oxide surge arrester (see 3.2.4). Surge arresters contain one or more nonlinear metal-oxide resistors (MO resistor). A nonlinear metal-oxide resistor (MO resistor) is the same as a variable metal-oxide resistor (MO varistor).

[EN 50526-1]

3.2.4
metal-oxide surge arrester without gaps
arrester having non-linear metal-oxide resistors connected in series and/or in parallel without any integrated series or parallel spark gaps

[EN 60099-4]

3.2.5
maximum continuous operating voltage of an arrester
U_c
designated permissible value of d.c. voltage that may be applied continuously between the arrester terminals

[EN 60099-4, mod.]

3.2.6
rated voltage of an arrester
U_r
voltage by which the arrester is designated. For d.c. traction systems the rated voltage is the maximum continuous operating voltage

[EN 60099-4, mod.]

3.2.7
charge transfer capability
maximum charge per impulse that can be transferred during the charge transfer test and during the operating duty test

[EN 50526-1, mod.]

3.2.8
discharge current of an arrester
impulse current which flows through the arrester

[EN 50526-1]

3.2.9
nominal discharge current of an arrester
I_n
peak value of lightning current impulse which is used to classify an arrester

[EN 60099-4]

3.2.10
high current impulse of an arrester
peak value of discharge current having a 4/10 µs impulse shape

[EN 60099-4]

3.2.11
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 shall be not longer than 20 µs

[EN 60099-4]

3.2.12
lightning current impulse
8/20 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

[EN 60099-4]

3.2.13
direct lightning current impulse
impulse defined by the charge Q and the peak value of the current impulse I_{imp}

[EN 50526-1]

3.2.14
long duration current impulse
rectangular impulse which rises rapidly to maximum value, remains substantially constant for a specified period and then falls rapidly to zero

[EN 60099-4]

3.2.15
switching current impulse of an arrester
the 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

[EN 60099-4]

3.2.16
continuous current of an arrester
I_c
current flowing through the arrester when energized at the continuous operating voltage

[EN 60099-4]

3.2.17
reference current of an arrester
I_{ref}
d.c. current defined by the manufacturer used to determine the reference voltage of the arrester

[EN 60099-4, mod.]

3.2.18
reference voltage of an arrester
U_{ref}
d.c. voltage applied to the arrester to obtain the reference current

[EN 60099-4, mod.]

3.2.19
residual voltage of an arrester
U_{res}
peak value of voltage that appears between the terminals of an arrester during the passage of discharge current

[EN 60099-4]

4 Systems and equipment to be protected

4.1 General

Electrical traction d.c. systems should be protected against overvoltages by surge arresters. Main field of application are in substations, at sectioning posts and at singular points along the contact lines.

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

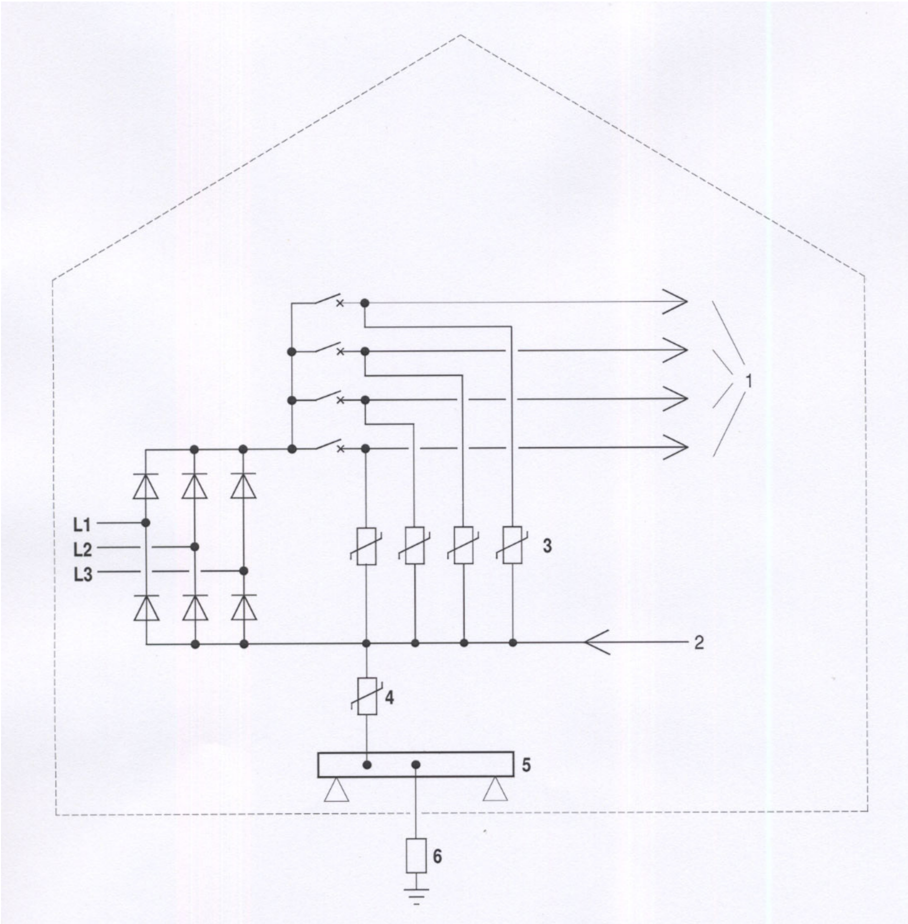
4.2 Substations

An important element of a lightning protection concept is the protection of the line feeders and return conductors in the substations with arresters (see Figure 1). The arresters have the following functions.

- The arresters A1, which are connected in the substation between the feeder circuit-breakers (cable connection) and the return circuit, reduce the overvoltages at the feeder circuit-breakers and the rectifiers, inclusive of their measuring and monitoring devices, in case of positive lightning strokes. In case of negative lightning strokes the diodes of the rectifier are conductive, but this does not endanger the elements.

- The arrester A2 between the return circuit and the structure earth is to limit overvoltages of the running rails. The arrester A2 is also important in case of direct lightning strokes into the running rails, e.g. if lines above earth have a conductor rail. The arrester A2 is not intended for protection against electric shock coming from impermissible rail potential.

NOTE Protection against electric shock is considered in EN 50526-2. When arresters A2 and protective devices as per EN 50526-2 are used at the same place, a coordination of both low voltage protective devices is needed (under consideration).



Key

1 feeder
2 return conductor
3 arrester A1
4 arrester A2
5 MEB
6 earth resistance

Figure 1 – Protective circuit in a substation (principle arrangement)

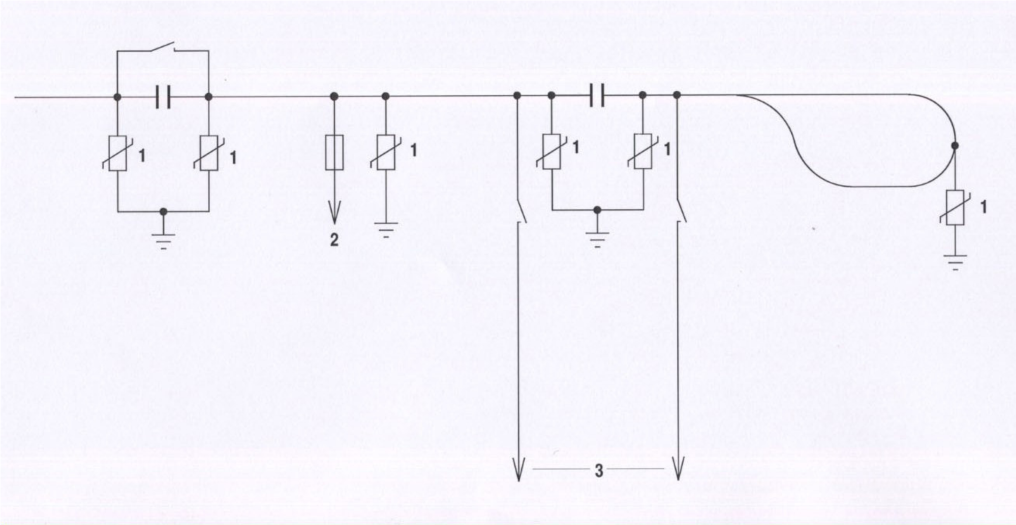
4.3 Overhead contact line system

Surge arresters should be installed between the overhead contact line system or return circuit and earth where discontinuities in the line are present and reflections of the overvoltage waves can occur, in particular (see Figure 2):

- 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);
- in 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).

Additional arresters can be necessary for track sections where frequent lightning strokes are likely, for instance on bridges or on elevated lines, and cross country lines.

The arresters A1 are preferably fitted at the height of the overhead contact line so that the electrical connection to the overhead contact line can be led in a short, straight way. Moreover, the arresters A1 are connected to the earth electrodes as directly as possible (see Figure 3). The arresters A1 and the cable between the arresters and the earth electrodes are insulated against the mast of the overhead contact line or the structure earth.



Key

1 arrester A1

2 current tap, e.g. switch heater

3 feeder from the substation

Figure 2 – Principle of a protective circuit of a line (outdoor system)

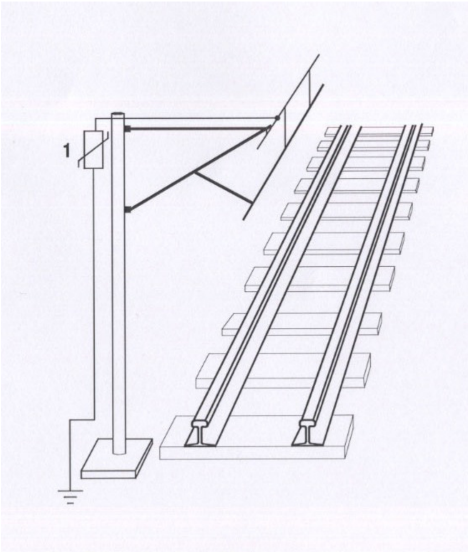
4.4 Return circuit

For stray current reasons the return circuit is not connected to earthing installations or earth according to EN 50122-2.

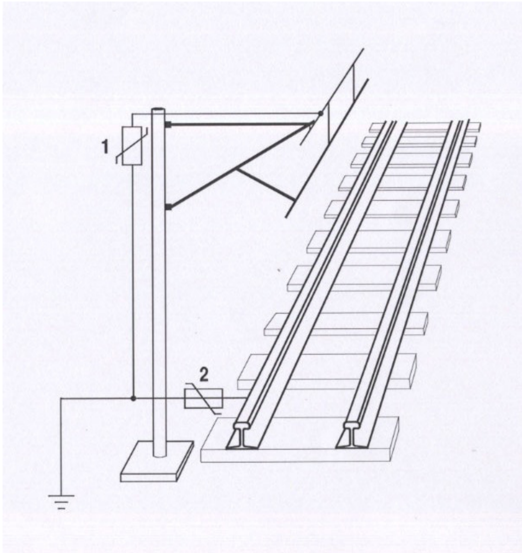
Running rails

To reduce the stray current corrosion, the resistance to earth of the running rails has to be high for d.c. traction systems. Consequently, the running rails are not suited as earth electrodes for lightning protection. Therefore, either low-resistance pole foundations, driven pipes as well as the reinforcement of tracks of reinforced concrete or separate buried earth electrodes are to be used as earth electrodes for lightning protection along the line dependent on the local conditions. Earthing resistance ≤ 10 Ω is regarded as sufficient (see for instance EN 62305-3).

It has to be born in mind that the discharged lightning energy may also appear on the tracks and that this can endanger the electrical or electronic equipment (e.g. switch controllers, signalling equipment, switch heaters) that is fitted near the tracks or in the tracks. This hazard can only be minimised if the equipment is provided with additional surge arresters against overvoltages.



a) **Protection of the overhead contact line**



b) **Protection of the overhead contact line and the running rail (return conductor)**

Key

1 arrester A1

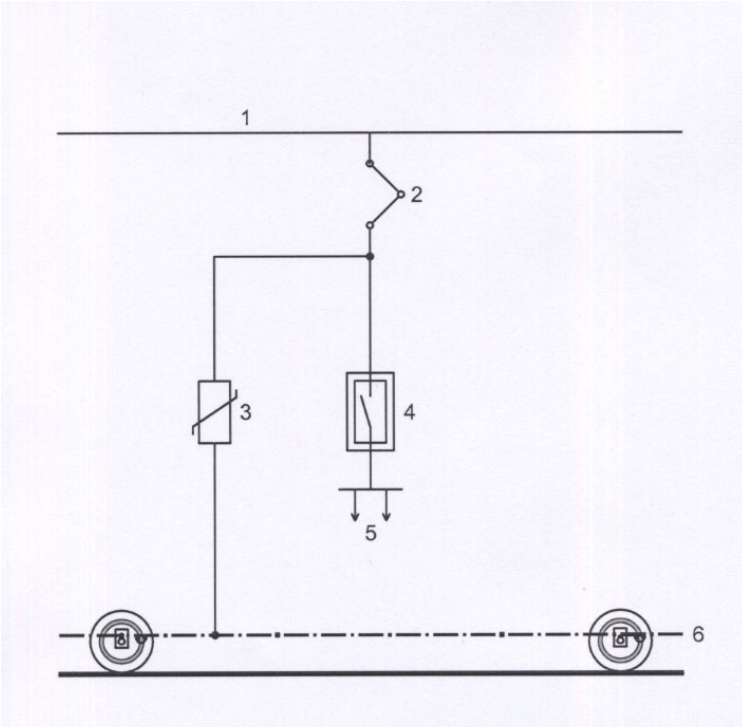
2 arrester A2

In both cases the running rails are insulated against earth.

Figure 3 – Installation of surge arresters on the overhead contact line and the running rails

4.5 Rolling stock

Surge arresters are installed on the vehicle roof close to the current collector, as shown in Figure 4.



Key

1 overhead contact line
2 current collector
3 arrester A1
4 main circuit breaker
5 electrical equipment of traction vehicle
6 vehicle body

Figure 4 – Surge arrester arrangement on a vehicle

5 Supply voltages

The relevant values for the supply voltages of the traction systems with the relevant admissible voltage ranges are given in EN 50163. See Table A.1.

6 Overvoltages

6.1 Lightning overvoltages

Traction systems can be treated the same 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 mostly 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's 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 and peak values up to 100 kA, and the switching current impulse with 30/60 wave shape and up to peak values of 2 kA. A specific wave shape 10/350 for direct lightning is also defined (see EN 50526-1). Normally, there is flash over at each pole (see below) leading after a few spans to an 8/20 wave shape, so that this wave shape is finally used for classifying surge arresters.

In case of a direct lightning to the conductor line, the charge is flowing in the form of two equal current waves in both directions, starting from the point of strike. A voltage wave is conjoined with 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 (single line), and 380 Ω for inclined overhead lines. For bus bars a value of 160 Ω can be used.

Considering the peak value of 30 kA, as mentioned above, and a surge impedance of 460 Ω, an overvoltage of 6 900 kV occurs, with a steepness of about 1 250 kV/µs. This overvoltage leads immediately to a flash over of one or more insulators, limiting the overvoltage to the value of the flash over voltage. This voltage is, depending on the type of insulator, in the range of 500 kV to 2 000 kV. None of the equipment in d.c. railway systems up to 3 000 V is insulated for such voltage stresses. Measures have to be taken to limit the overvoltages according to the rules of the insulation co-ordination.

6.2 Switching overvoltages

The circuit breakers used in direct current systems produce switching overvoltage. These depend on the type of breaker and on the magnitude of the applied d.c voltage in the traction system. The peak value of the switching overvoltage can be up to 3 times the nominal voltage of a traction system.

7 Function and characteristics of MO surge arresters

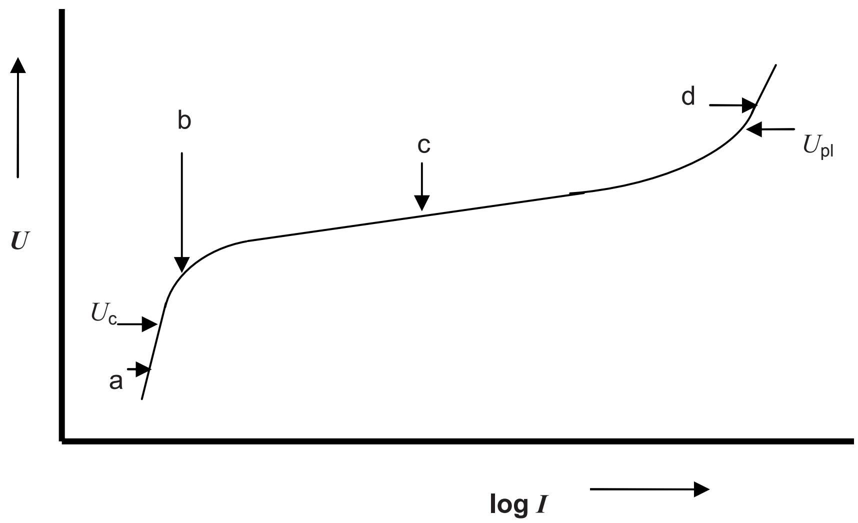
7.1 Basic function

Metal-oxide surge arresters have an extreme non-linear current voltage characteristic, which is described as

$$I = k \times U^{\alpha},$$

α being variable between $\alpha \leq 5$ and $\alpha \approx 50$. An exact value for α can only be provided for a very restricted range of the current in the characteristic curve.

The U-I characteristic of such an MO varistor is shown in Figure 5. I_n is the nominal discharge current, U_{pl} is the lightning impulse protection level of the surge arrester. It is defined as the maximum voltage between the terminals of the surge arrester during the flow of I_n. U_c is the maximum permissible continuous operating voltage.



Key

a lower linear part
b knee point
c strongly non-linear part
d upper linear part (“turn up” area)
U_c continuous operating voltage
U_{pl} lightning protective level

Figure 5 – Current-voltage characteristic of an MO surge arrester

7.2 Characteristics

The protection characteristic of an arrester is given by the maximum voltage U_{res} at the terminals of an arrester during the flow of a current surge. Generally, a lightning impulse protective level of $U_{pl} \leq 4$ p.u. is considered. This is a value that is generally accepted for the insulation coordination. The real residual voltage with nominal discharge current I_n (thus U_{pl}) can lie above or below that, depending on the type of arrester. If U_{pl} is set in a relationship with U_c of an arrester, it is possible to get very good information about the quality of the arrester performance with regard to the protective level. The smaller the ratio U_{pl}/U_c, the better is the protection taking also into account the switching overvoltages.

In addition to the residual voltage at I_n, the residual voltages at steep current impulse and at switching current impulse are also important. The residual voltage increases slightly with the current, but also with the steepness of the current impulse. Depending on the usage, the residual voltage at the steep current impulse and at switching current impulse must be taken into account besides the residual voltage at I_n.

7.3 Classification

Table 1 – Arrester classification and related parameters.

Arrester class	Nominal discharge current I_n kA	High current impulse I_{hc} kA	Switching current impulse I_{sw} A	Charge transfer capability Q As	Equivalent current value of a long duration current with T = 2 ms A
I	10	100	500	1,0	500
II	10	100	1 000	2,5	1 250
III	20	200	2 000	7,5	3 750

The equivalent current value for long duration current of T = 2 ms is given for information only.

MO surge arresters used in d.c. traction systems are classified by charge transfer capability and their nominal discharge current. Classes I to III correspond to increasing discharge requirements. The selection of the appropriate class shall be based on system requirements.

Typical areas of application are:

- Arrester class I
  - Application as line arresters to prevent insulator flashover due to lightning overvoltages. In such applications lightning protection structures, for instance earthed shielding wires, are essential for the protection concept. The arresters are intended to conduct the charge only in case the overvoltage is higher than the expected switching overvoltage in the system. This leads automatically to an unfavourable high protection ratio U_{pl}/U_c and a very short protective distance (see below).
  - Protection against induced overvoltages only.
  - Cases when surge arresters are intended to be co-ordinated regarding charge transfer capability and protection level with upstream surge arresters.
- Arrester class II
  - Standard application as A1 and A2 arresters in traction systems with nominal voltages of 750 V to 3 000 V. Protection of substations, feeders, overhead contact lines, running rails and rolling stock.
- Arrester class III
  - Areas with high risk of direct lightning to contact lines and rolling stock.
  - Areas without external lightning protection (lightning protection structures). However, it should be noted that surge arresters are not designed to withstand extreme lightning currents in case of direct strike into or very close to the arrester.
  - Applications where due to switching actions or possible system failures high charge transfer capability is required. The selection is generally based on system studies.
  - If a very low protection ratio U_{pl}/U_c is required.
  - In case of very high demands on electrical and mechanical withstand capability, reliability and safety for equipment.

Depending on the system requirements surge arresters of all classes of arresters can principally be used as A1 and A2 arresters. If A1 and A2 arresters are installed close together intentionally (e.g. in a substation or on a pole) they should be of the same class of arresters and have similar characteristics.

8 Insulation co-ordination and application of MO surge arresters

8.1 General

The insulation coordination is defined as the selection of the dielectric withstand required for equipment that is to be used at a specific site in a system. This process requires knowledge of the operational conditions in the system and the planned overvoltage protection devices, and the probability of an insulation fault on equipment which can be accepted under economic and operational aspects.

8.2 Principles of insulation co-ordination

Insulation co-ordination is the matching between the dielectric withstand of the electrical equipment taking into consideration the ambient conditions and the possible overvoltages in a system. For economic reasons, it is not possible to insulate electrical equipment against all overvoltages that may occur. That is why surge arresters are installed to limit the overvoltages up to a value that is not critical for the electrical equipment. Therefore, a surge arrester shall be designed that the maximum voltage that appears at the electrical equipment always stays below the guaranteed withstand value of the insulation of an electrical device. Figure 6 illustrates the principle of insulation coordination.

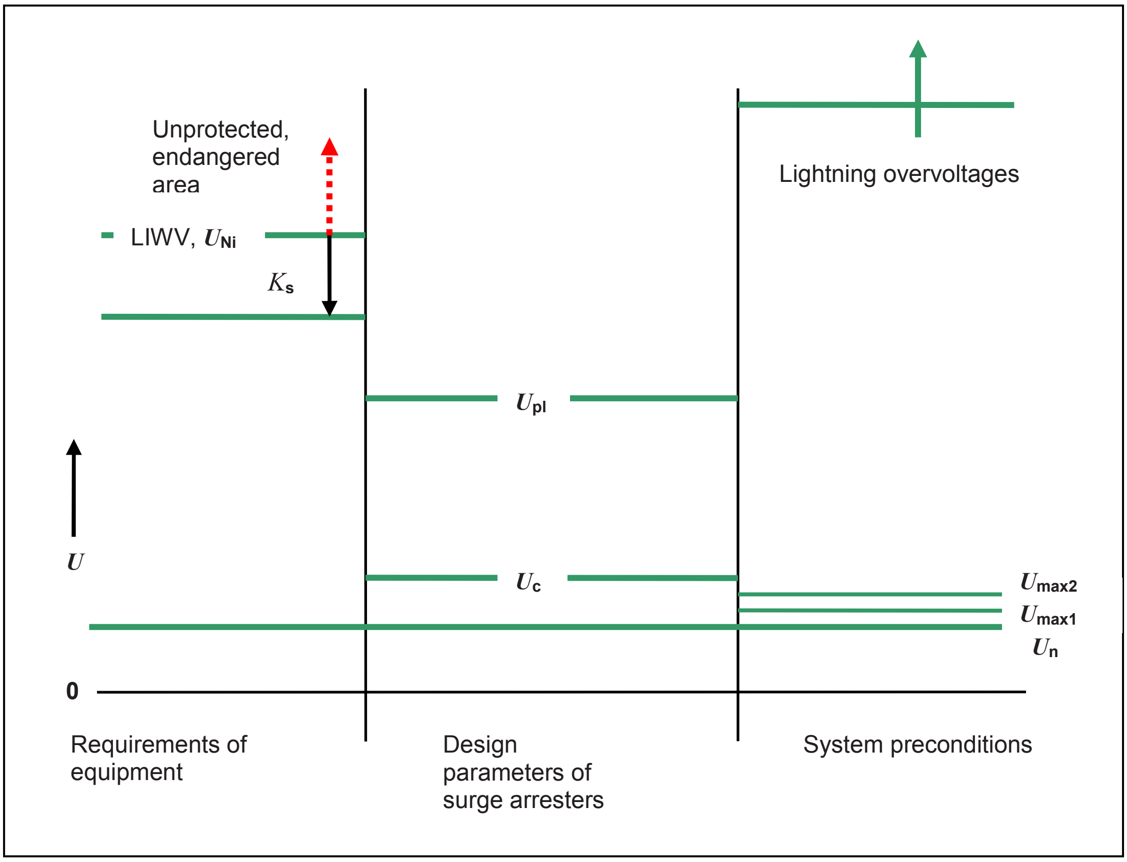


Figure 6 – Requirements and design of surge arresters

The lightning overvoltages depend on the lightning current and the surge impedance of the line. They can be extremely high, and if higher than the lightning impulse withstand voltage of the equipment, may destroy the insulation.

LIWV lightning impulse withstand voltage (see EN 60071-1), is similar to U_{Ni} rated impulse voltage (see EN 50124-1). In both definitions it is the withstand value against lightning impulse voltages with a wave shape of 1,2/50 µs.

K_s is the safety factor, considers possible ageing of the insulation and all other differences in dielectric strength between the conditions in service during life time and those in the standard withstand voltage test.

U_{pl} is the residual voltage of the surge arrester at nominal current I_n, and should be well below the LIWV and the considered safety margin K_s.

U_c is the continuous operating voltage of the surge arrester, and has to be equal or higher than U_{max2}.

U_n, U_{max1} and U_{max2} are the supply voltages according EN 50163, see Table A.1.

The requirements of the equipment are based on EN 50124-1, the system preconditions are coming from EN 50163.

Table 2 – Insulation levels

U_n V	U_{Nm} V	U_{Ni} V
750	900	12 000
1 500	1 800	18 000
3 000	3 600	40 000

The values for U_{Ni} are according the overvoltage category OV4: circuits which are not protected against external or internal overvoltages (e.g. directly connected to the contact or outside lines) and which may be endangered by lightning or switching overvoltages (see EN 50124-1). For overvoltage categories OV1, OV2 and OV3 other (lower) values apply.

Described in the following paragraphs are the basic principles for selection of the MO surge arresters in traction systems.

The MO arrester can fulfil its function of protection properly if the lightning impulse protection level U_{pl} lies clearly below the lightning impulse withstanding voltage (LIWV) of the electrical equipment to be protected, the safety factor K_s is also to be taken into consideration.

The point is to set the voltage-current characteristic of the arrester in a way that both requirements are met.

The lightning impulse withstand voltage LIWV (withstand voltage of the insulation) is relatively high compared to the system voltage, as can be seen in Figure 6. This automatically results in a large margin between the maximum admissible voltage at the electrical equipment to be protected and the lightning impulse protection level.

8.3 Protective distance

8.3.1 General

The protective distance concept for traction systems is similar to the one used for medium voltage systems.

The higher its lightning impulse withstand voltage (LIWV) lies above the residual voltage of the arrester at nominal discharge current I_n, the better the equipment is protected against lightning overvoltages

It should be noted that the specified residual voltages U_{res} from the data sheets apply for the terminals of the arrester, which means they are valid only for the place where the arrester is installed. The voltage at the devices that are to be protected is always higher than the voltage that is directly at the arrester terminals in view of the reflections of the overvoltages at the end of lines.

Therefore, the overvoltage protection no longer exists if the arrester is placed too far from the device to be protected. The protective distance L is understood to be the maximum distance between the arrester and the equipment, at which the latter is still sufficiently protected.

8.3.2 Travelling waves

Voltage and current impulses having a rise time shorter than the travelling time of an electromagnetic wave along the line, travel along the line as travelling waves. This means that disregarding damping, the current and voltage impulse travels along the line without changing its form. Therefore, it is in another place at a later time.

Current and voltage are connected to one another because of the surge impedance of the line. The surge impedance results from the inductivity and capacitance per unit length of the line, disregarding the ohmic resistance per unit length and the conductivity of the insulation.

$$Z = \frac{\sqrt{L'}}{\sqrt{C'}}$$

where

L' is the inductivity per unit length in H/km;

C' is the capacitance per unit length in F/km.

Only the voltage impulses are important when analyzing the overvoltages.

When a voltage travelling wave on a line reaches a point of discontinuity, i.e. a change in the surge impedance, part of the voltage is “reflected” backward and a part is transmitted forward. This means that voltage decreases and voltage increases appear on the connections of the overhead lines to the cable, and at the end of the line. Especially at the end of the line, such as at open connections or transformers, there appear reflections, which lead to a doubling of the voltage. The height of the voltage for each moment and for each place on the line is the sum of the respective present values of all voltage waves.

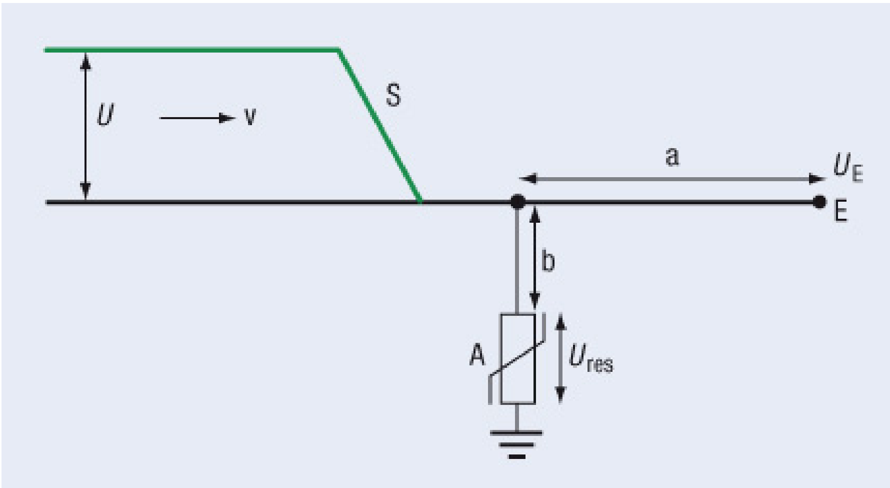
8.3.3 Protective distance *L*

On the overhead line in Figure 7 an overvoltage U travels as a travelling wave with the speed v towards the line end E. At point E there is the equipment to be protected. For the following analysis it is considered that the equipment to be protected is high-ohmic (transformer, open circuit breaker). When the travelling wave reaches E, it is positively reflected and the voltage increases to $2 \times U$. The function of arrester A is to prevent unacceptable high voltage values at the equipment to be protected. Under the simplified assumption that the front of wave steepness S of the incoming overvoltage wave is time constant, the following relationship applies for the maximum value U_E:

$$U_E = U_{res} + \frac{2 \times S \times (a+b)}{v}$$

where

v = 300 m/µs.



Key

U incoming overvoltage wave
v velocity of the travelling wave
S front steepness of the overvoltage
A arrester
U_{res} residual voltage of the arrester
a, *b* length of the connections
E end of the line. Connected is, for example, a transformer or an open circuit breaker
U_E voltage at the end of the line

Figure 7 – Assumption for the calculation of the voltage at the open end of a line and for the determination of the protective distance *L*

A protection factor K_s is recommended between the LIWV of the equipment and the maximum lightning overvoltage that occurs. This protection factor takes into consideration, among other things, the possible ageing of the insulation and the statistic uncertainties in defining the lightning impulse withstanding voltage of the equipment. K_s = 1,15 is recommended for the internal insulation and K_s = 1,05 for the external insulation. K_s = 1,2 is proposed for the calculation of the protection distance in d.c. railway systems.

$$\frac{LIWV}{K_s} \geq U_E = U_{res} + \frac{2 \times S \times L}{v}$$

$$L = a + b$$

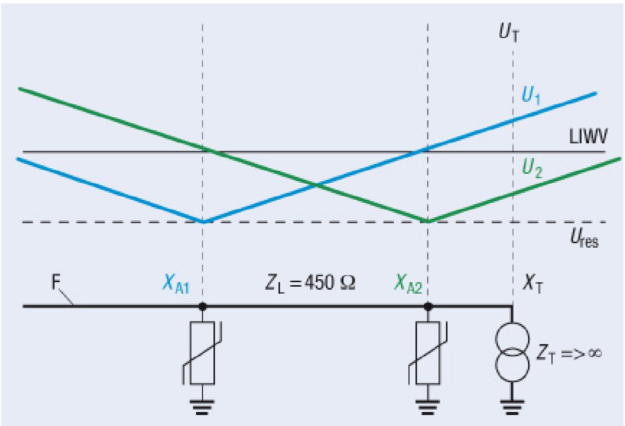
The required equation for the protection distance is:

$$L = \frac{v}{2 \times S} \times \left(\frac{LIWV}{K_s} - U_{res} \right)$$

It should be mentioned that the given approximation for L is valid in the strict sense only for $b = 0$, for practice, however, it gives sufficiently precise values.

It is certainly to be assumed that the arrester and the equipment to be protected are connected to the same earthing system. To be observed as a principal rule, the arrester should be installed as close as possible to the equipment to be protected. The connections must be executed on the high voltage side and the earth side short and straight. Especially the connection b should be executed as short as possible. In this way it makes sense to lead the overhead line first to the arrester and from there directly to the bushing of the transformer, for example.

According the travelling wave theory, there appears a funnel shaped voltage increase, which has its lowest value at the installation place of the arrester. From this it results that the surge arrester should be installed as close as possible to the equipment protected.



Key

F	overhead contact line
X_{A1}	installation point 1 of surge arrester
X_{A2}	installation point 2 of surge arrester
Z_L	surge impedance of the overhead contact line
X_T	end of the line (e.g. installation point of a transformer)
Z_T	impedance at the end of the line
U_T	voltage at the end of the line
U_1	voltage funnel for installation point 1
U_2	voltage funnel for installation point 2
U_{res}	residual voltage of surge arrester
LIWV	withstand voltage of the insulation

Figure 8 – Voltage funnel and illustration of protective distance

8.3.4 Expected steepness *S* of lightning overvoltages in railway systems

The steepness S of the incoming overvoltage wave must be known in order to determine the protective distance as it is above described.

The repetition rate of the lightning strokes and the overvoltages related to them can only be taken from statistics. That is why it is not possible to give any generally applicable information about the steepness of the overvoltages that occur. An assumed steepness is always connected to the probability of an event.

The statistics for faults and damages show that in Central Europe about 8 lightning strokes occur per year and 100 km in overhead lines of medium voltage systems. However, it must be observed that in regions with unfavourable topographical conditions and especially regions with high thunderstorm activity there may occur up to 100 lightning strokes per year and 100 km overhead lines. Assuming that 8 lightning strokes occur per year and 100 km in overhead lines and substation equipment, it can be expected that the steepness reaches S = 1 550 kV/µs.

8.4 Protection level

Of prime importance here is the lightning impulse protection level U_{pl} and if necessary, the protection level at steep current impulses.

Generally speaking, the protection level should be as low as possible to ensure optimal protection. The protection ratio U_{pl}/U_c is fundamentally important. The smaller the ratio, the lower the protection level with the same U_c and the better the protection. If a very low protection level is technically absolutely necessary in a specific case, it is possible to choose an arrester with a better protection ratio. As a rule, this is an arrester with a higher energy class, because these arresters have MO resistors with a larger diameter as an active part. The choice of a MO arrester with the same U_c, but a higher energy class offers better protection in the system although the operational safety stays the same and it also provides a higher energy handling capability. Moreover, a MO arrester with a lower protection level always provides a larger protective distance.

Therefore, the choice of an arrester or the comparison of different products should also take into consideration the protection ratio U_{pl}/U_c in addition to the nominal discharge current and the charge transfer capability.

8.5 Surge arresters connected in parallel

Surge arresters are generally considered to be stand alone devices. They are acting according their voltage-current characteristic independent of other equipment or other surge arresters in the same line.

Two or more surge arresters may be intentionally connected in parallel

- to increase the charge transfer capability,
- to reduce the protection level, and
- to co-ordinate protection level and charge transfer capability (e.g. if a substation is connected via a cable to the overhead line).

In such cases the manufacturer has to be contacted and informed that the surge arresters are intended for parallel connection. It is essential that the characteristics of the surge arresters are carefully matched to ensure correct function. The surge arresters have to be installed close to one another to avoid possible decoupling effects due to the inductances of the connections.

9 Selection of MO surge arresters

9.1 Continuous operating voltage U_c

The arrester continuous operating voltage U_c should be set to the highest non-permanent voltage U_{max2} that is

$$U_c \geq U_{max2}.$$

According to Table A.1 the following standard values result.

For networks with a nominal voltage of

U_n = 750 V follows **$U_c \geq$ 1 000 V**

U_n = 1 500 V a **$U_c \geq$ 1 950 V**, and

U_n = 3 000 V a **$U_c \geq$ 3 900 V**.

For traction systems with nominal voltage 600 V the same principles as for systems with 750 V apply. Thus, the continuous operating voltage is $U_c \geq$ 1 000 V.

If these values are not in the data sheets, the next higher arrester continuous operating voltage is to be chosen.

9.2 Arrester class

Examples for the selection of the appropriate arrester class are given in 7.3.

9.3 Mechanical considerations

MO surge arresters on rolling stock are exposed to special mechanical stress. That is why all arresters which are used on rolling stock should be tested according to EN 61373, shock and vibration tests.

Annex A
(informative)

Supply voltages

Table A.1 – Supply voltages

Electrification system	Nominal voltage U_n V	Highest permanent voltage U_{max1} V	Highest non-permanent voltage U_{max2} V
d.c.	750	900	1 000
mean values	1 500	1 800	1 950
	3 000	3 600	3 900

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EN 60099-4	Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems (IEC 60099-4, mod.)
EN 60099-5	Surge arresters – Part 5: Selection and application recommendations (IEC 60099-5, mod.)
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EN 61643-11	Low-voltage surge protective devices – Part 11: Surge protective devices connected to low-voltage power systems – Requirements and tests (IEC 61643-1, mod.)
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Cigré Electra TB 287	Protection of MV and LV Networks Against Lightning – Part 1: Common topics

[1)] At draft stage.

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