

# Application Guidelines

## Overvoltage Protection



Dimensioning, testing and application of metal-oxide surge arresters in railway facilities

Cover: ICN at Zurich main station (Photo: SBB)

First edition: June 2000

Second edition, revised and expanded:

October 2007

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## CONTINUOUS DEVELOPMENT AND COMPLETION

*The Application Guidelines Overvoltage Protection: Dimensioning, testing and application of metal oxide surge arresters in railway facilities (first edition June 2000) was much welcomed by our customers and other interested persons. The further development of the products makes it necessary to revise and complete the application guidelines. In the present application guide there are to be found not only the adaptation to the newest standards but also devices for protection of persons against too high contact voltage. The new structure is meant to bring more clarity.*

*Mr Bernhard Richter, responsible for product management, application of the overvoltage protective devices and quality assurance in the Surge Arresters Division of ABB Switzerland Ltd. revised the first edition of the brochure from 2000 and presents here in a precise and clear form the technical bases of the metal-oxide surge arresters and low voltage limiters, and their application in railway facilities.*

*Mr Richter is an active member in different working groups of IEC (International Electrotechnical Commission), CENELEC (Comité Européen de Normalisation Electrotechnique), CIRED (Congrès International des Réseaux Electriques de Distribution) and CIGRÉ (Comité International des Grands Réseaux Electriques).*

*Hopefully you, as a reader, will find a lot of useful information in this new edition of the brochure. We welcome amendments, suggestions and qualified hints for improving this brochure.*

*ABB Switzerland Ltd.*

Wettingen, October 2007

# CONTENTS

	<b>PREFACE</b>			
<b>1</b>	<b>INTRODUCTION</b>	<b>5</b>	<b>5</b>	<b>CURRENTS IN RAILWAY FACILITIES</b>
			5.1	Traction currents
			5.2	Fault currents
			5.3	Stray currents
<b>2</b>	<b>SURGE ARRESTERS</b>	<b>6</b>	<b>6</b>	<b>LIGHTNING CURRENTS AND OVERVOLTAGES</b>
2.1	MO surge arresters	6		
2.1.1	MO resistors	7		
2.1.2	Insulation made of silicone	7		
2.1.3	Construction of the arresters	7		
2.1.4	Technical data of the arresters	8		
2.1.5	Arresters of ABB and typical application in railway facilities	9		
2.2	Service conditions	10		
2.2.1	Overload behaviour	10		
2.2.2	Elevated ambient temperature	10		
2.2.3	Mechanical stability	10		
2.2.4	Pollution and cleaning	10		
2.2.5	Flying sparks	11		
2.2.6	Altitude adjustment for arrester housings	11		
2.3	Tests	12		
2.3.1	Definitions	12		
2.3.2	Type tests	12		
2.3.3	Routine and acceptance tests	13		
2.3.4	Special tests	13		
<b>3</b>	<b>LOW VOLTAGE LIMITERS</b>	<b>15</b>	<b>7</b>	<b>OVERVOLTAGE PROTECTION IN A.C. RAILWAY NETWORKS</b>
3.1	Functioning of the low voltage limiters	15	7.1	Overvoltage protection of overhead lines and locomotives
3.2	Low voltage limiters of the type HVL	16	7.1.1	a.c. voltage networks 25 kV, 50 Hz
3.2.1	Technical data of the HVL	16	7.1.2	d.c. voltage networks 15 kV, 16,7 Hz
3.2.1.1	HVL 120-0,3	16		
3.2.1.2	HVL-ED 1	17		
3.2.2	Tests	17	<b>8</b>	<b>OVERVOLTAGE PROTECTION IN D.C. RAILWAY NETWORKS</b>
			8.1	Protection of d.c. traction vehicles
			8.2	Dimensioning of the surge arresters
			8.2.1	Urban traffic (< 1000 V)
			8.2.2	Long-distance traffic
<b>4</b>	<b>VOLTAGES IN RAILWAY FACILITIES</b>	<b>18</b>	<b>9</b>	<b>COMBINATION OF SURGE ARRESTERS AND LOW VOLTAGE LIMITERS</b>
4.1	Supply voltages of railway networks	18		
4.1.1	Frequencies of the a.c. systems	18	<b>10</b>	<b>DIRECTIONS FOR INSTALLATION</b>
4.1.2	Nominal voltages of d.c. railway systems	19		
4.1.3	Switching overvoltages	20	<b>11</b>	<b>STANDARDIZATION</b>
4.2	Touch voltages / accessible voltages	20		
			<b>12</b>	<b>CONCLUSION</b>
			<b>13</b>	<b>REFERENCES</b>

## 1 | INTRODUCTION

The overvoltage protection of the electrical energy supply installations of railway facilities has an increasing importance nowadays, not only for railways which are supplied with a.c. voltage but also increasingly for d.c. voltage railways.

The long-distance railway system is electrified with 3 kV d.c. voltage on over 70,000 km rails (in year 2000, that means about 38 % of the total length of the rails of the electrical railways) and with 1,5 kV d.c. voltage on more than 20,000 km (about 11 %). That means that about half of the world-wide railway length of the long-distance traffic is operated with direct current. The length of the electrified rails by the outer suburban service, including local trains, which operate with a d.c. voltage under 1000 V, is about 25,000 km. These figures show the extent of the d.c. voltage systems in railways and also the importance of an optimal overvoltage protection which is adjusted to the specific demands of the d.c. voltage railways.

The application and dimensioning of metal oxide surge arresters (MO surge arresters) without spark gaps in alternating current networks with 50 Hz and 16,7 Hz of the railway supply is not very different from the one of the general energy supply. On the other hand the dimensioning and the load of the MO surge arresters in d.c. railway facilities have not been extensively dealt with until now. Moreover, the modern MO surge arresters without spark gaps and with silicon insulation make it possible to develop solutions for special applications.

The fact that the electrical railways expand very rapidly, like for instance in China, India and in urban agglomerations, shows the necessity to develop new and more optimal overvoltage protection devices.

Overvoltages in electrical supply networks result from the effects of lightning strokes and switching actions and cannot be avoided. They endanger the electrical equipment, because,

due to economical reasons, the voltage withstand capability of the insulation cannot be designed for all possible cases. Therefore, an economical and reliable service calls for extensive protection of the electrical equipment against unacceptable overvoltages. In fact this applies to all networks of the energy supply.

We will shortly present here different kinds of overvoltage and the possibility of reducing them. For general information you may use the Application Guidelines Overvoltage Protection: Dimensioning, testing and application of metal oxide surge arresters in medium voltage networks [1] and further literature.

We only want to mention here that lightning strokes are the most dangerous threat for railway networks. That is why it is necessary to reduce the overvoltage to a safe value through appropriate protection. MO surge arresters without spark gaps give outstanding protection in this situation. In this brochure the technical outdated protection appliances like arcing horns and spark gap arresters, as well as surge arresters in porcelain housings, are not dealt with any more.

In some applications, for instance on overland lines in regions with high risks of lightning and on bridges, parts of the total lightning current may stress the MO surge arrester directly due to direct or nearby lightning. Therefore, lightning current parameters, resulting overvoltages, and energy stresses need to be considered.

In order to avoid the stray current corrosion the rails in d.c. railways are mostly insulated against earth. In case of a defect (for instance the breaking of the overhead line) or some operational cases, inadmissible contact voltages can appear which may be dangerous for persons. The newly designed protection devices, which protect not only the appliances against overvoltages but also persons against contact voltages, make it possible to develop new protection concepts.

## 2 | SURGE ARRESTERS

The so-called “conventional” surge arresters were almost exclusively installed in networks of the electrical energy supply until the middle of the eighth decade of the last century. They consist of a series connection of SiC resistors and spark gaps, which are placed in porcelain housing, and are generally called “spark gap arresters”.

Spark gap arresters have a couple of disadvantages: They reduce overvoltages only when the breakdown voltage of the spark gaps is achieved. The breakdown voltage of the spark gaps depends on the steepness of the incoming voltage which results in a bad protection especially for steep overvoltages.

If the outside insulation of the arrester is polluted, the potential distribution can shift along the active part, and this can cause unwanted sparkover in the spark gaps, which in the end may destroy the arrester.

If spark gap arresters are connected in parallel only one arrester switches on during an overvoltage. That is the arrester that has the lowest response voltage. This arrester reduces the overvoltage to a value below that of the sparkover voltage of the other parallel arresters, and in this way it prevents the sparkover of the other arresters. Therefore it is not possible to distribute the energy of the surge among more spark gap arresters which are connected in parallel.

In the spark gap arresters the follow current flows three times longer with 16,7 Hz than with 50 Hz which overloads the spark gap arrester having the same continuous voltage as for 50 Hz. In the past, spark gap arresters, which were used in networks of 16,7 Hz, had an inconvenient higher voltage than the arresters of 50 Hz, and implicitly a worse protection level.

The problem of using spark gap arresters in d.c. networks lies especially in the fact that the arc that is produced through a sparkover has to be extinguished.

If an arrester with porcelain housing is overloaded it is always possible that the porcelain insulator cracks and that the porcelain pieces that fall down can cause injuries.

Arcing horns have no insulation housing and therefore their disadvantage lies in the fact that their function very strongly depends on their state and the environment condition (erosion of the electrodes, humidity, ice, pollution, foreign particles, animals, etc.). It is also possible that the d.c. arc, once arisen, cannot be extinguished any more, because there is no natural current zero.

### 2.1 MO surge arresters

There are two essential improvements in the arrester technology nowadays compared to the spark gap arrester. One of them is the metal-oxide resistor that replaced the series connec-



Figure 1: MO resistors (selection) manufactured by ABB.

tions of spark gaps and SiC resistors, and the other one is the replacement of the porcelain housing through polymeric material.

**2.1.1 MO resistors**

The MO resistors make up the active part of the MO surge arrester. They are made of different metal oxides in powder form which are compressed and sintered in the form of round blocks [2]. The diameters of the MO resistors of ABB Switzerland Ltd., made for all the networks of the electrical energy supply and for special applications, lie between 38 mm and 108 mm. The height of the MO resistors is typically between 1 mm and 46 mm. The diameter of the MO resistors determines the carrying capacity of the current, the height of the MO resistors (or resistor stack) determines the voltage in continuous operation, and the volume of the blocks the energy capacity.

The contact areas of the MO resistors are metallised up to the edge of the block with soft aluminium, the surface of the housing is coated

with glass. In this way the MO material of the MO resistors of ABB Switzerland Ltd. is completely covered. Figure 1 shows a selection of MO resistors. The diameter of the MO resistors correlates with the line discharge classes corresponding to IEC/EN 60099-4, as shown in Table 1 [3]. As this specification deals only with a.c. voltage networks with voltage rated  $\geq 3$  kV, the tests and demands that are mentioned here can only partially be applied to the d.c. voltage networks.

Line discharge class acc. IEC/EN 60099-4	1	2	3	4	5
Diameter of MO resistor in mm	38 / 42	47	62	75	108
Rectangular wave, 2 ms, in A	250 / 350	550	1000	1350	2000
Energy absorption in kJ/kVU <sub>c</sub>	3,6 / 3,5	5,5	9,0	13,3	19,8

Table 1: Correlation of typical MO resistors to the line discharge classes. The given energy relates to the operating duty test, and is the energy injected to the arrester before proving the thermal stability of the arrester under applied continuous operating voltage.

**2.1.2 Insulation made of silicon**

Silicon is an excellent insulation material as compared to different insulation materials like porcelain, glass and other synthetic materials like EPDM. The advantageous properties of silicon for the insulation of MO surge arresters are:

- hydrophobicity of the material
- self-extinguishing behaviour
- no toxic elements
- mechanical unbreakability
- small weight

**2.1.3 Construction of the arresters**

The patented principle of construction of the ABB arresters with silicon direct-moulding consists of two electrodes which are connected to one another through two or more glass-fibre reinforced elements. It results a hard cage or frame, which guarantees the mechanical



strength. The MO resistors are arranged inside this frame. Additional metal cylinders with the same diameter as the MO resistors fill the inside completely, forming in this way a uniformly round active part. The MO blocks are pressed together with a bolt in the centre of the lower electrode. The bolt is secured in the end position, providing in this way each arrester with the same contact pressure. The active part is placed into a form and completely moulded in silicon. As a result the surge arrester, which is completely sealed and tight, has no void inside. Figure 2 shows a MO surge arrester of type POLIM-H, which was manufactured according to this technique, before and after being moulded in silicon. The flexible method of construction (modular concept) provides the possibility of changing the form of the arrester in order to fit each necessity.

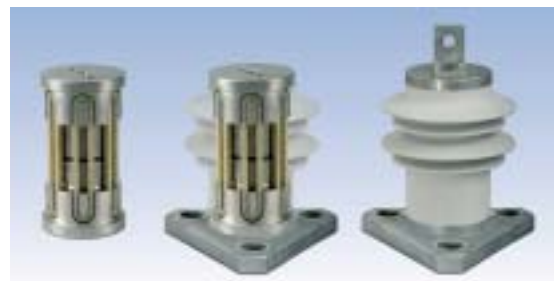


Figure 2: MO surge arrester type POLIM-H ... ND. Left: active part before moulding. Middle: scheme of design. Right: complete arrester with base plate and terminal.

**2.1.4 Technical data of the arresters**

The demands on the arresters depend on the operational conditions and the type of the electrical equipment to be protected. For the railway facilities, which have different voltage networks and special demands, both electrical and

mechanical, ABB offers a selection of different types of MO surge arresters. The safety and the ecological aspect are especially taken into consideration with all the arresters.

Table 2 presents main technical data of the arresters, applicable for railway facilities. Railway facilities are serviced with both d.c. and a.c. systems and the arrester types are operational for both d.c. and a.c. voltage networks. Therefore the definitions and data are slightly different which requires a splitting of the table.

Table 2: Main technical data of ABB arresters which are used in railway facilities.

Arrester type a.c. systems	$I_n$ kA	$U_{res}/U_c$	$I_{hc}$ kA	$E/U_c$ kJ/kV	Rectangular wave A (t = 2 ms)	MPSL* N	Torsion Nm	Vertical load N
MWK / MWD	10	3,07	100	5,5	550	850	68	1200
POLIM-I	10	3,07	100	5,5	550	3500	100	2000
POLIM-S	10	3,0	100	9,0	1000	5700	100	3000
POLIM-H	20	3,19	100	13,3	1350	8000	100	4000
Arrester type d.c. systems	$I_n$ kA	$U_{res}/U_c$ , dc	$I_{hc}$ kA	$E/U_c$ , dc kJ/kV	Rectangular wave A (t = 2 ms)	MPSL* N	Torsion Nm	Vertical load N
POLIM-C ... ID	10	3,2	100	4,3	550	-/-**	-/-	-/-
POLIM-C ... ND	10	3,2	100	4,3	550	690	50	1000
POLIM-H ... SD	20	2,7	100	10,5	1350	2500	50	1000
POLIM-H ... ND	20	2,7	100	10,5	1350	8000	100	4000
POLIM-X ... ND	20	2,7	200	21,0	2700	16000	100	1500
POLIM-R ... -1 ND	20	2,7	100	10,5	1350	-/-	-/-	-/-
POLIM-R ... -2 ND	20	2,4	200	19,0	2400	-/-	-/-	-/-
POLIM-ID	40	3,0	400	37,8	4860	-/-	-/-	-/-










\* Maximum permissible service load. The MPSL is, according to the definition, the force which can be applied on the highest arrester of an arrester series during 60 s until 90 s, without resulting in a permanent deflection more than 5 % of its height.

\*\* Arresters without information about mechanical data are not allowed to be loaded with bigger mechanical forces at the high voltage connection. Information about the mechanical loading capacity is to be received from the manufacturer.

### 2.1.5 Arresters of ABB and typical application in railway facilities

The following pictures show the actual portfolio of MO surge arresters of ABB for application in d.c. and a.c. railway systems.

Further information can be found at [www.abb.com/arrestersonline](http://www.abb.com/arrestersonline)

				
<p><b>POLIM 4.5 ID</b></p>	<p><b>POLIM-X . . ND</b></p>	<p><b>POLIM-H . . ND</b></p>	<p><b>POLIM-H . . SD</b></p>	<p><b>POLIM-R . .1/2ND</b></p>
<p>Special surge arrester for d.c. railway installations with <math>U_n = 3</math> kV. Extremely high energy absorption capability with excellent protection level. For indoor applications only.</p>	<p>Very powerful surge arrester for d.c. railway networks up to <math>U_n = 3</math> kV. For areas with high lightning activities and danger of direct lightning.</p>	<p>For use in d.c. railway installations up to <math>U_n = 3</math> kV. Protection of electric locomotives and substations. Very rugged design, especially developed for railway applications.</p>	<p>For use in d.c. railway systems up to <math>U_n = 3</math> kV. Thanks to its compact design it is particularly suitable for use in substations and trolleys.</p>	<p>For special applications in d.c. networks. Very high energy absorption capability with simultaneously very good protection level.</p>
				
<p><b>POLIM-C . . ND</b></p>	<p><b>POLIM-C . . ID</b></p>	<p><b>POLIM-H . . N</b></p>	<p><b>POLIM-S . . N</b></p>	<p><b>POLIM-I . . N</b></p>
<p>Protection of d.c. installations including railway systems, transformers and motors.</p>	<p>For special applications in medium voltage systems, for motor and cable sheath protection, also for d.c. applications.</p>	<p>Surge arrester with particularly high mechanical and electrical strength. Recommended for use in railway installations and on rolling stock. Typical station class arrester for a.c. systems with <math>f = 50</math> Hz and 16,7 Hz.</p>	<p>Surge arrester with high energy absorption capability and good protection level in rugged mechanical construction. For installation in a.c. systems with <math>f = 50</math> Hz and 16,7 Hz.</p>	<p>Suitable for the protection of medium voltage transformers and cable installations as well as railway installations. Typical intermediate surge arrester in rugged mechanical construction. For use in a.c. systems with <math>f = 50</math> Hz and 16,7 Hz.</p>

## 2.2 Service conditions

The service life of the arresters could be of about 30 years under normal operating conditions if they are properly designed for the respective system voltage and for the expected electrical and mechanical loads. The normal service conditions for the MO surge arresters are to be found in [3]:

- ambient temperature  $-40^{\circ}\text{C}$  to  $+40^{\circ}\text{C}$
- solar radiation  $1,1\text{ kW/m}^2$
- altitude up to 1000 m above sea level
- frequency of a.c. voltage between 48 Hz and 62 Hz
- power frequency voltage at the arrester connections not higher than the continuous operating voltage  $U_c$  of the arrester

All the arresters of ABB fulfil or even exceed these service conditions. Some special cases are discussed in the following chapter.

### 2.2.1 Overload behaviour

Any arrester can be overloaded. The causes can be extremely high lightning currents or a so-called voltage transition, a short circuit between two different voltage levels. In all these situations there is in fact an energy overloading. In such a case of overloading the MO resistors either sparkover or break down and create as a rule a permanent short circuit. An arc results inside the arrester and the current in this arc is defined by the short circuit power of the network. With the ABB arresters with silicon housing there is no danger of explosion or shattering in case of an overload. There is no air space between the active part of the arrester and its silicon insulation, thus there is no place for the pressure to build up. The occurring arc (or sparks) escapes the silicon insulation immediately as it occurs and so it is free. Because of their special construction the arresters are safe against explosion up to the highest short circuit currents.

### 2.2.2 Elevated ambient temperature

The ABB arresters (a.c. and d.c. voltage) are guaranteed to function flawlessly up to  $40^{\circ}\text{C}$  ambient temperature. This also includes the maximum solar radiation of  $1,1\text{ kW/m}^2$  for outdoor arresters. If there are heat sources in the vicinity of the arrester, the increase of the ambient temperature must be taken into account, and the value of  $U_c$  increased if necessary. If the ambient temperature exceeds  $40^{\circ}\text{C}$ ,  $U_c$  must be increased by 2 %, for every 5 K of temperature elevation. This correction is possible up to maximum  $80^{\circ}\text{C}$  ambient temperature.

### 2.2.3 Mechanical stability

The arresters of ABB are operationally reliable even in areas of high earthquake activity. The arresters may partially take on the support function or, as line arresters, they may have the function of suspension insulators. By such operational situations it is necessary to inform the manufacturer. The values given in Table 2 are not to be exceeded. The arrester types which are to be applied on rolling material are delivered with a reinforced base plate and are tested acc. [4] under vibration and shock conditions.

### 2.2.4 Pollution and cleaning

Silicon is the best insulating material in case of pollution. This is mainly because the material is water-repellent (hydrophobic). Silicon arresters behave more favourably under conditions of heavy pollution than porcelain housed arresters or other polymer insulation materials.

Decisive for the long-term behaviour under pollution of an insulation made out of a polymeric material is the dynamic behaviour of the hydrophobicity, which is originally almost always very good [11].

Depending on the material a loss of hydrophobicity can be permanent or temporary. The silicon in contrast to other polymeric materials is able to gain back the hydrophobicity after losing it for a while.

Arresters which are applied on rolling material and are regularly washed are not affected in any way. Environmentally safe cleaning agents do affect neither the arrester function nor the properties of the insulation.

### **2.2.5 Flying sparks**

The silicone used in the described ABB arresters is a hardly inflammable and self-extinguishing material. Tests have shown that blazing hot particles, which emerge by the de-contacting of the pantograph or by braking, do not negatively affect the silicon housing of the arrester. There is no danger that the arrester can be ignited by the sparks, or that the insulation resistance of the housing may be decreased through humidity or rain because of the particles that adhere to the surface.

### **2.2.6 Altitude adjustment for arrester housings**

The ABB arresters can be used without any housing adjustment up to a height of 1800 m above sea level. At higher altitudes the air density is so low that the withstand voltage of the arrester housing (external flashover) is not sufficient any longer. In this case the unaltered active part of the arrester (same protection level) must be placed in an elongated housing with a longer flashover distance. As a reference point one may consider that for every 1000 m over 1800 m above sea level the flashover distance must be increased by 12 %. For example, at an altitude of 3300 m above sea level the flashover distance of the housing must be 18 % longer than that of a standard arrester. It is necessary to mention that the flashover distances of arresters for lower voltage levels are relatively large initially, exceeding the minimum requirements of the withstand voltage. Thus, it should be checked for each single case whether the normal housing possesses the sufficient withstand voltage for the application in higher altitudes.

### 2.3 Tests

The requests and tests for MO surge arresters in a.c. railway facilities are not different from the ones for arresters in networks of the electric power supply (refer to the bibliography no. [1] and [3]). The additional tests, which are necessary especially for the railway facilities, are shown in the following chapters.

The requests and tests for arresters in fixed d.c. railway installations are to be found in the standard EN 50123-5 [12]. The most important of them and especially the partially different definitions and test procedures for the railway application [3] will be explained shortly in the following lines.

Tests with lightning currents, or with stresses equivalent to lightning currents, are under consideration in the standardisation working groups. For the time being such tests have to be agreed upon between manufacturer and user.

#### 2.3.1 Definitions (See also chapter 4)

##### Rated voltage ( $U_r$ )

The maximum d.c. voltage value between terminals which the surge arrester has to withstand in the operating duty test. This voltage corresponds to the temporary voltage increase  $U_{\max 2}$  acc. EN 50163 [5], which is allowed to appear for maximum 5 minutes.

##### Maximum continuous operating voltage of the arrester ( $U_c$ )

The highest voltage which may be applied unlimited between the terminals of the arrester.

##### Nominal discharge current of an arrester ( $I_n$ )

Peak value of the lightning current corresponding to IEC 60099-4. The nominal discharge current is used for classifying the arresters.

##### Protective voltage level of the arrester ( $U_{res}$ )

The highest residual voltage at the nominal discharge current  $I_n$ .

The relation  $U_{res}/U_c$  shows the protection level of the arrester. The smaller the relation  $U_{res}/U_c$ , the better is the protection characteristic of the arrester.

#### 2.3.2 Type tests

The type tests are tests which are carried out only once to show that a special arrester type operates properly.

The type tests for MO surge arresters without spark gaps, which are used in a.c. voltage networks, are described in the standard IEC/EN 60099-4. In EN 50123-5 there is the description of the type tests for MO surge arresters in d.c. systems, fixed installations.

The following type tests are to be carried out:

- testing of the insulation withstand voltage of the housing
- testing of the residual voltage
  - with steep current impulse
  - with lightning current impulse
  - with switching current impulse
- testing with rectangular current waves
- operating duty test (operating duty test with high current impulse)
- d.c. voltage versus time characteristic
- tightness test
- proof of the pressure relief / overload test (by agreement between customer and manufacturer)

The tests are similar to the ones for the MO surge arresters which are used in a.c. networks. Only the procedure of the operating duty test is different from the one of the MO surge arresters in a.c. networks. This is why we describe here minutely only the operating duty test and the ageing test for the MO resistors applied in d.c. voltage systems.

### Operating duty test

- measuring of the residual voltage at  $I_n$
- conditioning (4 groups of 5 applications of  $I_n$ , superimposed on  $1,2 U_c$ )
- high current impulse  $4/10 \mu s$
- heating in the oven up to  $60^\circ C$
- high current impulse  $4/10 \mu s$
- rated voltage  $U_r$  for 300 s
- continuous voltage  $U_c$  for 1800 s
- measuring of the residual voltage at  $I_n$
- visual inspection

In the current EN 50123-5 it is pointed out that if there are not sufficient direct current sources for this test, it is possible to carry out the test with a.c. voltage (alternative procedures), by agreement between the manufacturer and the customer.

### Accelerated ageing test

This test has to show that the power losses of the arrester in the network under applied continuous operating voltage do not increase with time. In order to demonstrate this, the power losses are measured in a time-accelerated ageing test under increased load. It is decisively important that this test should be carried out with d.c. voltage. It is known that MO material, which has a long-time stability with the alternating voltage load, is not necessarily long-time stable with direct voltage load. The results of ageing tests which are carried out with a.c. voltage are not transferable to the application in d.c. voltage networks.

All ABB MO resistors which are installed in arresters for d.c. voltage networks fulfil the most strictly demands towards the long-time stability under d.c. voltage load.

### 2.3.3 Routine and acceptance tests

The routine tests are carried out corresponding to IEC/EN 60099-4, and they are not different from the tests for arresters which are used in a.c. voltage networks of the general electrical energy supply. Arresters for d.c. systems and for 16,7 Hz systems are normally tested in the routine test with equivalent 50 Hz voltages and currents.

Acceptance tests are in principle to be agreed upon by the manufacturer and the customer.

### 2.3.4 Special tests

The present EN 50123-5 relate to EN 60099-4, 1993 (or IEC 60099-4, 1991) with regard to the tests for MO surge arresters. This edition describes only the demands and the tests for MO surge arresters with porcelain housing in a.c. networks. That is why different tests are only restrictively applicable to arresters with insulation made out of polymeric materials, or are still under discussion.

The demands and the tests for the arresters with insulation made out of polymeric materials described in the latest edition of IEC 60099-4, 2006, will be taken into consideration in the revised edition of EN 50123-5.

During the development of the MO surge arresters with polymeric insulation there were carried out all kind of tests. These special tests and development tests are here shortly mentioned. For more information please refer to [\[1\]](#).

### Weather-ageing test

Pollution and ageing tests under extreme weather conditions, which are carried out on complete arresters, with long duration stress (1000 h) or cyclical load (total 5000 h) have to inform about the behaviour of the arrester in the network. The cyclical 5000 h test is the most meaningful test for the critical examination of the long-term behaviour of the dynamic hydrophobicity (the return of the hydrophobicity after a temporary loss).

### Test with high air humidity

This long-time test over several years was carried out at the Technical University of Tampere in Finland as a research project. During all the time the test samples were in a climatic chamber under applied voltage in a relative air humidity of 95 % up to 100 % and a temperature of 30 °C up to 35 °C.

### Cold and icing tests

In order to test the behaviour of the arresters at very low temperatures, tests were carried out in air up to -60 °C and icing tests up to -40 °C.

### UV tests

The positive behaviour of the used material (silicon) was shown in long-term tests in outdoor test fields and in labs under strong UV radiation for more than 1000 h.

### Sparking

Through the jumping of the pantographs and during braking it is possible that hot rubbed-off particles may arise. These may spray as sparks on the nearby arrester. In order to demonstrate that the silicon insulation is insensitive to this kind of stress the arresters were exposed to a forced spark stress. Afterwards the resistance of the insulation was tested.

### Overload tests

In the new IEC 60099-4, 2006 there are methods described to proof the short circuit behaviour of different arrester designs. The arresters, depending on their type and rating, are tested with short circuit a.c. currents up to 63 kA, 0,2 s. Short circuit currents in d.c. railway systems can reach up to 45 kA. Consequently, short circuit tests have to be carried out with d.c. currents with reference to IEC 60099-4, 2006.

### Vibration and shock tests

MO surge arresters on rolling material are exposed to special mechanical stress. That is why all the arresters which are used on rolling material are delivered with a reinforced base plate for the appliance on locomotives. The arresters on these base plates were exposed to a vibration and shock test according to IEC 61373 [4].

## 3 | LOW VOLTAGE LIMITERS

Low voltage limiters are protective devices that are used in fixed installations of d.c. traction systems in order to diminish inadmissible high potential differences between different earthed metallic parts, especially between the rails and earthed metallic parts. They are therefore protective against too high touch voltage.

As a rule the rails are not directly earthed in order to avoid stray currents in d.c. traction systems. In case that an overhead line breaks down (falling down of the conductor) an inadmissible high touch voltage may occur between the rails and the nearby metallic objects (masts, railings, etc.). Even the normal train operation can lead to inadmissible touch voltages, as for instance during maintenance work in the stations. In these cases the low voltage limiters protect persons effectively.

Low voltage limiters are not to be used to protect installations against lightning and switching overvoltages.

### 3.1 Functioning of the low voltage limiters

The operational principle of the commercially available low voltage limiters consists of two electrodes made of metal, which face one another and are insulated against each other. They produce a permanent short circuit through fusing if the voltage gets beyond a certain maximum value. The insulation consists mainly of a thin ring made out of an insulating material. In another concept there is a gas discharge tube used as insulation; it also gives a certain protection against impulse overvoltages.

Almost all commercially available low voltage limiters produce a non-reversible short circuit between two potentials at the moment of the sparkover.

The low voltage limiters which are placed along the rails and in the stations are stressed with overvoltages coming from lightning or switching. Investigations have shown that most com-

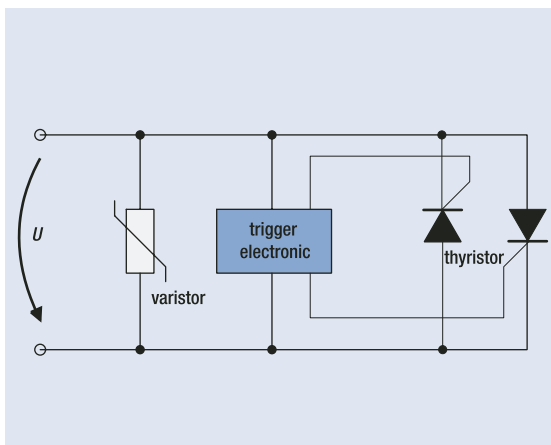


Figure 3: Principle circuitry of the bipolar low voltage limiter HVL 120-0,3.

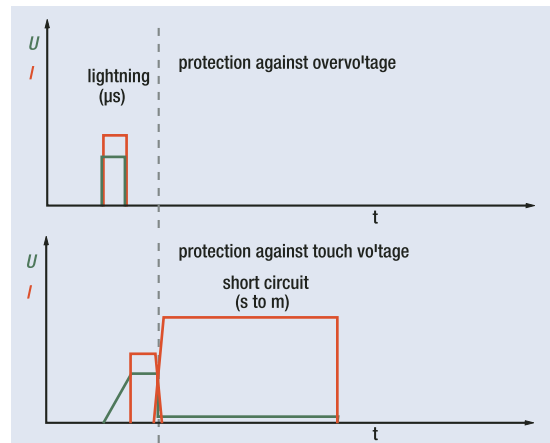


Figure 4: Function of HVL. Overvoltages, for instance generated by lightning, are limited by the MO resistor. In this short time frame the thyristors are not fired (above). In case of failures in the system, e.g. braking of overhead line with contact to the rails, the voltage rise is relatively slow. If the voltage reaches a given value the thyristors are fired, and the current commutates from the MO resistor to the conducting thyristor (below). The voltage at the HVL is almost zero, the total current is flowing through the thyristor. If the current becomes zero (e.g. clearing of the fault) the thyristor extinguishes and becomes high ohmic again, as in the original state.

mercial low voltage limiters go in the short circuit state after being stressed with lightning overvoltage.

### 3.2 Low voltage limiters of the type HVL

The HVL (Hybrid Voltage Limiter) is a full reversible low voltage limiter which has a high energy handling capability. It combines the necessary person protection against touch voltage and the protection of the installation against lightning and switch overvoltages. The HVL consists of a parallel connection of a MO resistor with two anti-parallel connected thyristors. The MO resistor plays the part of a surge arrester and restricts the overvoltages from lightning and switching (time duration between some micro-seconds and some hundred micro-seconds). A potential rise between the rail and the earthed installation parts is short-circuited by the thyristors, providing protection against touch voltages (period of time between milliseconds and minutes). Figure 3 shows the principle circuit of the HVL, and Figure 4 the principle function.

The MO resistor in the HVL has the same diameter and the same electrical characteristics as the MO resistors in the surge arresters POLIM-H ... ND and POLIM-H ... SD. These surge arresters are employed as A1 surge arresters in the protection concept, which is later to be described (chapter 8.2). That is why the HVL can be combined with the A1 surge arresters in order to reach an optimal protection concept. This protection concept can be used on the overhead lines and in the stations, exchanging the A2 surge arrester with a HVL.



Figure 5: Low voltage limiters type HVL with terminals: bipolar HVL 120-0,3, mainly used in d.c. systems with  $U_n = 750$  V.



Figure 6: Low voltage limiters type HVL with terminals: unipolar HVL-ED 1, developed for application in d.c. systems with  $U_n = 3000$  V.

#### 3.2.1 Technical data of the HVL

The HVL is, as described above, a combination between a MO surge arrester and a parallel low voltage limiter, based on a thyristor. For this reason the main technical data for both elements are given.

##### 3.2.1.1 HVL 120-0,3

- limiting voltage:  $102\text{ V} \pm 18\text{ V}$  (maximum limiting voltage 120 V). If this voltage is reached one of the two thyristors triggers and produces a short circuit (maximum voltage  $< 3\text{ V}$ ).
- current according to the test of reversibility: 300 A during 60 s. This current can be applied 10 times consecutively (with a break of 1 min. every time) with full reversibility.
- long-duration current: 500 A during 1800 s (without guarantee of reversibility).
- short circuit current: 20 kA d.c. during 0,1 s.

Data of the integrated MO resistor:

- nominal discharge current  $I_n$ : 20 kA 8/20  $\mu\text{s}$
- residual voltage  $U_{res}$  at  $I_n$ : 380 V
- line discharge class according to IEC: 4
- lightning current withstand capability: 10 kA 10/350  $\mu\text{s}$

### 3.2.1.2 HVL-ED 1

A unipolar HVL with the following data was developed for special applications in a traction network of 3 kV:

In conducting direction:

- limiting voltage: 120 V  $\pm$ 5 V (maximum limiting voltage 125 V). If this voltage is reached the thyristor triggers and produces a short circuit (maximum voltage <3 V).
- current according to the test of reversibility: 300 A during 60 s. This current can be applied 10 times consecutively (with a break of 1 min. every time) with full reversibility.
- short circuit current: 10 kA half-sine wave with 50 ms duration.

Data of the integrated MO resistor:

- nominal discharge current  $I_n$ : 20 kA 8/20  $\mu$ s
- residual voltage  $U_{res}$  at  $I_n$ : 950 V
- line discharge class according to IEC: 5
- lightning current withstand capability: 25 kA 10/350  $\mu$ s

### 3.2.2 Tests

The type tests for the HVL 120-0,3 were carried out with reference to EN 50123-5, IEC 61992-5 respectively. The type tests include:

- measurement of the d.c. flashover voltage
- measurement of the leakage current
- long-term current capability
- current-withstand voltage and impulse voltage test with follow current
- reversibility test

In addition the conformity to the EMC regulations was tested.

The behaviour and the operational capability of the HVL 120-0,3, together with other voltage limiters and MO surge arresters, were tested in extensive field tests in a tram service station [9]. The HVL-ED 1 was developed in a close co-operation with the customer and was tested according to customer specifications [10].

## 4 | VOLTAGES IN RAILWAY FACILITIES

The values for the operating voltages of the railway facilities with the admissible deviations are defined in the European Standard EN 50163 [5]. Some definitions and voltage values, which are important for the surge arrester and the overvoltage protection, are shortly explained in the following paragraphs.

### Voltage $U$

The potential at the train's current collector (pantograph), measured between the supply conductor and the return conductor.

### Nominal voltage $U_n$

The designated value for a system.

### Highest permanent voltage $U_{max1}$

The maximum value of the voltage likely to be present indefinitely.

### Highest non-permanent voltage $U_{max2}$

The maximum value of the voltage likely to be present for maximum 5 min.

### Overvoltage

A transient rise of voltage lasting less than 2 s.

### Long-term overvoltage

A transient rise of voltage, lasting typically more than 20 ms, due to low impedance phenomena (e.g. a rise in substation primary voltage).

### Medium-term overvoltage

A transient rise of voltage, lasting typically less than 20 ms, due to high impedance phenomena (e.g. the opening of a circuit breaker).

### Short-term overvoltage

A transient rise of voltage, lasting less than 20  $\mu$ s (e.g. lightning strokes).

### 4.1 Supply voltages of railway networks

In Table 3 the parameters of the most important supply voltages are given. Figure 7 shows schematically the highest values of voltages which arise in networks, depending on the period of time.

#### 4.1.1 Frequencies of the a.c. systems

The nominal value of the frequency in the 15 kV network is 16,7 Hz. It lies in the range of 16,7 Hz up to 17 Hz. The nominal value of the frequency in the 25 kV network is 50 Hz. It lies in the range of 49 Hz up to 51 Hz.

Table 3: Parameters of the most important supply voltages

\* The voltage values for  $U_{max2}$  can become 800 V in the 600 V net and 1000 V in the 750 V net, in case of regenerative braking.

\*\*  $U_{max3}$  is a calculated value for an overvoltage at  $t = 20$  ms.

Electrification system	Nominal voltage	Highest permanent voltage	Highest non-permanent voltage	$U_{max3}^{**}$ V
	$U_n$ V	$U_{max1}$ V	$U_{max2}^*$ V	
<b>d.c.</b> (mean values)	600	720	770	1015
	750	900	950	1269
	1500	1800	1950	2538
	3000	3600	3900	5075
<b>a.c.</b> (r.m.s. values)	15 000	17 250	18 000	24 311
	25 000	27 500	29 000	38 746

#### 4.1.2 Nominal voltages of d.c. railway systems

In addition to the preferential voltages 750 V, 1500 V and 3000 V, which are given (and standardised) in Table 3, there are some other voltages in the d.c. systems which are in use. These voltages and their application areas are shown in Table 4.

Type of train	Nominal voltage
Mine railway (under ground)	220 V and 500 V
Mine railway (above ground)	1,2 kV, 1,5 kV, 2,4 kV and 3 kV
Tramline, trolley bus	600 V and 750 V
Underground railway	750 V, 1,2 kV and 1,5 kV
Suburban railway	750 V to 3 kV
Long-distance railway	1,5 kV and 3 kV

Table 4: Nominal voltages and their application.

In the suburban service (trams, trolley bus) the nominal voltage is below 1000 V, because of potential danger that may be caused by a too high voltage.

Figure 8 shows the example of the measured voltage  $U$  at the current collector of a modern suburban vehicle during the undisturbed operation. The voltage curve at the current collector is not only influenced by the power demands of the respective vehicle, but also by the demands of other vehicles which are in the network, and by their position to the supplying substation. The illustrated short-time voltage peaks appear, for instance, at the passing of a neutral section of contact line, at the jumping of the current collector, or at the beginning of the braking process, and they are provoked by the units of power control of the vehicle. Figure 9 shows in another example the voltage  $U$  at the current collector during a test ride.

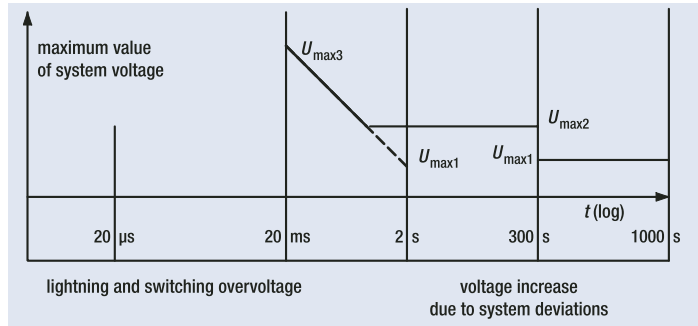


Figure 7: Highest values of voltage occurring in the systems depending on time duration.

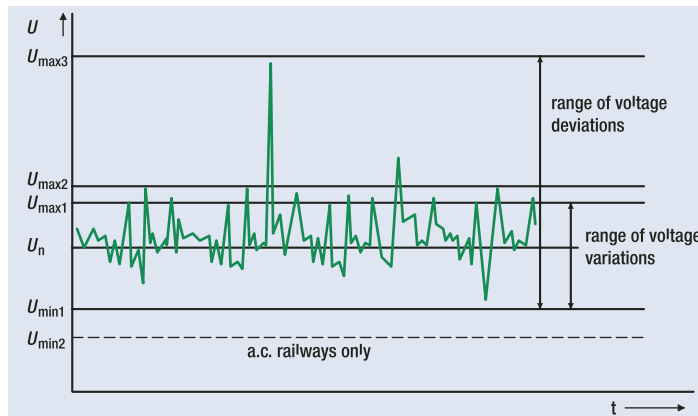


Figure 8: Voltage  $U$  at the current collector of a traction vehicle for a period of 15 min.

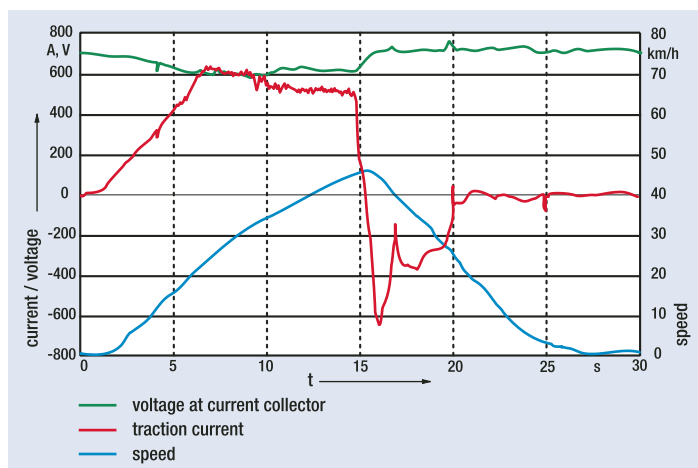


Figure 9: Characteristics of a test ride, acceleration from 0 to 45 km/h with maximum force, afterwards generative braking.

### 4.1.3 Switching overvoltages

The power switches which are used in d.c. networks produce switching overvoltage. These depend on the type of breaker, and on the magnitude of the d.c. voltage. Table 5 shows typical breakers, their switching overvoltages and their total disconnecting times.

Type of breaker	Total disconnecting time ms	Switching overvoltage $U/U_n$
Plunger type	>10	2...3
Magnetically blown	> 8	1,5...2,1
Thyristor breaker with vacuum chamber	< 1	< 2

Table 5: Disconnecting times and switching overvoltage of the d.c. breakers in railway networks.

### 4.2 Touch voltages / accessible voltages

Besides the protection of the appliances and the installations against overvoltages, which are caused by lightning strokes and switching, it is also very important to take into consideration the protection of persons against inadmissible high voltages in the rail surroundings. The highest admissible voltages, considering the protection of persons, are to be found in the EN 50122-1 [8] and they are prescribed for the rail potential. They are valid for rail tracks, railway stations, substations and technical buildings. Depending on the time condition the admissible voltage is between 120 V and 940 V. In [8] it is defined:

#### Accessible voltage

The part of the rail potential that can be reached by persons during operation, taking into consideration that the way of the current goes from one hand to both feet or from one hand to the other (horizontal distance of 1 m to a contact part).

#### Touch voltage

The voltage that results in case of a fault condition between two parts which can be simultaneously touched.

The highest admissible voltages for the d.c. railways are divided in three areas:

- highest admissible contact voltage  $U_t$  for the period of time  $t = 0,02$  s until 0,5 s (short time occurrences)
- highest admissible contact voltage  $U_a$  for the period of time  $t = 0,6$  s until 300 s (time limited occurrences)
- long-time occurrences during which the accessible voltage  $U_a$  may not be higher than 120 V (in workshops and similar places there are only 60 V admissible)

Figure 10 shows the time dependence of the admissible voltages [15].

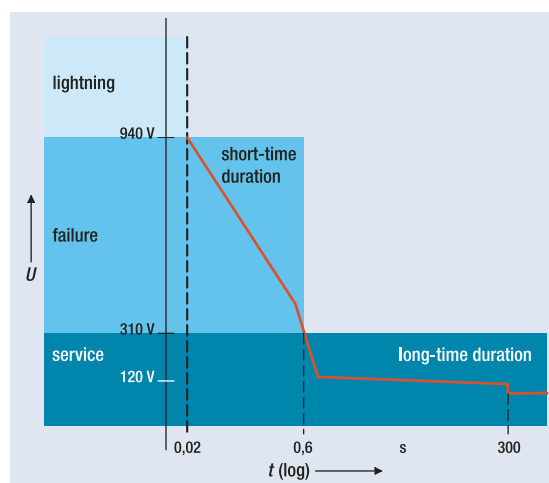


Figure 10: Admissible touch voltages under the influence of time.

## 5 | CURRENTS IN RAILWAY FACILITIES

### 5.1 Traction currents

Due to the high power needed for modern d.c. railways (approximately 500 kW for trams, and 1500 kW for suburban trains), and the relatively low voltages used, the traction currents can be rather high. Starting currents can be in the range of 1700 A for trams, and up to 3000 A in 3 kV systems.

### 5.2 Fault currents

In case of shorts to earth or short circuits it is possible that electrical currents between some 100 A and up to 45 kA can flow, depending on the distance between failure and supply station (measured values). For high power trains, short circuit currents up to 85 kA have been calculated.

Short circuits in the contact line installations of d.c. traction systems appear rather often compared to the short circuits in the energy supply of a country. For long-distance trains one may count on three short circuits per track km and year. With the suburban services the short circuits are generally much more often. The main reasons for the appearance of short circuits are:

- traction vehicles running in earthed sections
- flashover of insulators
- damages from the exterior (e.g. objects or animals on the contact line, storm, lightning stroke, vandalism)
- damages of the current collectors, of the traction vehicles or in the contact line system

### 5.3 Stray currents

A special problem with the operation of d.c. railways is the stray current corrosion. With d.c. railways the current necessary to transmit the electrical power to the traction vehicle flows back through the rails. Because of the relatively small contact resistance between the rails and the earth, a part of the reverse current flows out of the rail into the surroundings of the present position of the train and back through the earth to the rectifier substation. If there are buried metal installations inside the area of influence of the railway, as for instance pipes or cable coverings, a part of the reverse current also flows through these buried metal devices.

At the exit points of the current out of the metal it comes to electro-chemical corrosion, because the earth plays the part of an electrolyte. In this way, for instance, during a year there are taken away 9,1 kg iron, 10,4 kg copper and 33,4 kg lead by a permanent current flow of only one ampere.

In order to reduce these negative influences, which become more and more important with the increasing of the necessary transmission power of d.c. railways, the rails at the new devices are laid insulated. On the other hand this can lead to the increasing of the rails' potential and, in this way, inadmissible high touch voltage may appear.

## 6 | LIGHTNING CURRENTS AND OVERVOLTAGES

The lightning parameters are derived from statistical analysis of world-wide lightning measurements [13]. 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:

Current peak value	30 kA
Rise time	5,5 $\mu$ s
Time to half value	75 $\mu$ s

Extreme lightnings can reach peak values up to 200 kA, with half-time values of 2000  $\mu$ s.

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  $\mu$ s and a half time of 20  $\mu$ s (wave shape 8/20  $\mu$ s).

Other standardized currents are the high current impulse with the wave shape 4/10  $\mu$ s and peak values up to 100 kA, and the switching current impulse with 30/60  $\mu$ s wave shape and peak values of up to 2 kA.

For the purpose of testing lightning protection structures and the so-called lightning current arresters, which are used in lightning protection systems, a lightning current with the wave shape 10/350  $\mu$ s and peak values up to 200 kA is used.

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 hitting. 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. railway systems are 460  $\Omega$  (single line), and 380  $\Omega$  for inclined overhead lines. For bus bars values between 155  $\Omega$  and 162  $\Omega$  can be used.

Considering the peak value of 30 kA, as mentioned above, and a surge impedance of 460  $\Omega$ , an overvoltage of 6900 kV occurs, with a steepness of about 1250 kV/ $\mu$ s. This overvoltage leads immediately to a flashover of one or more insulators, limiting the overvoltage to the value of the flashover voltage. This voltage is, depending on the type of insulator, in the range of 500 kV to 2000 kV.

None of the equipment in d.c. railway systems up to 3000 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.

The same values of overvoltages can be assumed in a.c. railway systems with  $U_n = 15$  kV and  $U_n = 25$  kV.

## 7 | OVERVOLTAGE PROTECTION IN A.C. RAILWAY NETWORKS

The European 16,7 Hz railway networks are constructed differently in comparison with the 50 Hz transmission networks of the railway facilities, which are rather similar to those of the public energy supply enterprises. Figure 11 shows as an example the railway current supply of the Swiss National Railways (SBB) and the application points of the surge arresters. Both of the current conductors of the 132 kV networks have a voltage of 66 kV versus earth. The middle point of some transformer is effectively grounded. In Germany and in Austria the transmission networks are grounded through coils. In case that in such a transmission network a single phase earth fault takes place, the other phase, which has no fault, can take a higher voltage versus earth. The MO surge arresters without spark gaps can bear even an increased 16,7 Hz voltage during an earth fault. The choice of the continuous operating voltage  $U_c$  takes place according to the TOV capability of the arrester. In the present case a POLIM-H 84 N is used with  $U_c = 84$  kV, which has a residual voltage of  $U_{res} = 268$  kV at the standard nominal discharge current of  $I_n = 20$  kA. Accordingly the arresters for the transformer neutral have an  $U_c = 44$  kV.

### 7.1 Overvoltage protection of overhead lines and locomotives

When designing the arresters for the different network voltages, three characteristics are to be taken into consideration: the highest continuous voltage that arises in the network, the protection level of the arresters, and the energy absorption capability of the arrester. The most important characteristic taken into consideration by the design is that the arrester in the network should be stable from the thermal point of view, no matter which stresses appear. The strong voltage fluctuations in the supply line due to the operating conditions make it necessary to lay the continuous voltage of the arrester  $U_c$  over the highest continuous voltage of the network  $U_{max1}$  (see Table 3 and Figure 7). The highest non-permanent voltage  $U_{max2}$  can appear for maximum 5 min. according to the specification, but it is not known how often and in which time interval this voltage increase may appear. As the modern ABB MO surge arresters have a very favourable protection level and a high energy absorption capability, it is possible to lay the continuous operating voltage  $U_c$  of the arrester similar or higher  $U_{max2}$ , that is

$$U_c \geq U_{max2}$$

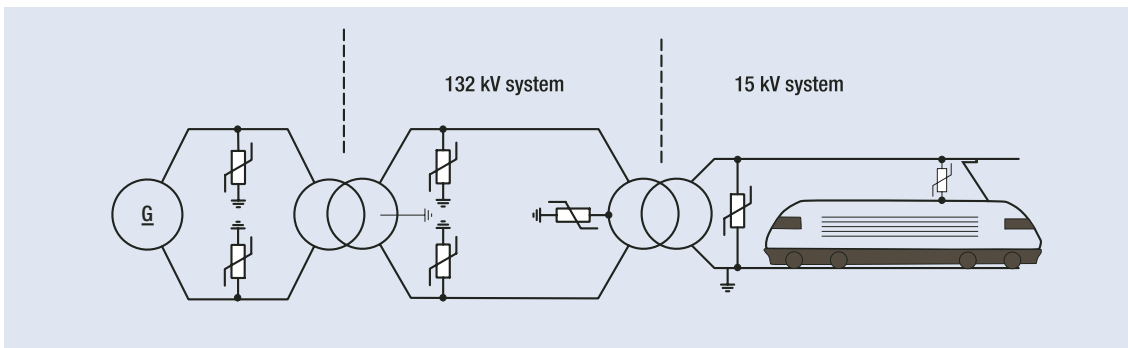


Figure 11: Schematic representation of a 16,7 Hz railway current supply and the application of surge arresters.

**7.1.1 a.c. voltage networks 25 kV, 50 Hz**

With  $U_{\max 2}$  from Table 3 results a continuous operation voltage of the arrester of

$$U_c \geq 29 \text{ kV}$$

The types POLIM-H 29 N and POLIM-I 31 N are used on the locomotives. With modern e-locomotives the high voltage of the current collector is brought into the inner part of the locomotive through a cable, and this requires a co-ordination concept of the arrester for a good overvoltage protection. On the roof of the locomotive there are two POLIM-H 29 N installed at the current collectors, and in the inner part of the locomotive there is a POLIM-I 31 N installed in front of the main power breaker.

**7.1.2 a.c. voltage networks 15 kV, 16,7 Hz**

With  $U_{\max 2}$  from Table 3 results a continuous operating voltage of the arrester of

$$U_c \geq 18 \text{ kV.}$$

With the SBB and other Swiss Railways the arresters POLIM-H 18 N are installed on the locomotives and the types POLIM-S 18 N are used at the overhead lines.

The German Railway (DB) for instance uses a co-ordination concept with the locomotive BRE 101, which is set in the interregional trains, and installs on the roof an arrester of the type POLIM-H 18 N and in the inner part of the locomotive the type POLIM-I 20 N.

## 8 | OVERVOLTAGE PROTECTION IN D.C. RAILWAY NETWORKS

The protection of the electrical railways has the task, in case that faults appear, to:

- prevent damages to the installation or try to reduce them as much as possible
- assure the availability of the railway energy supply as much as possible
- prevent or reduce the endangering of life through direct or indirect influence of the fault voltages.

Especially with d.c. railways it is very important to take into consideration not only the usual high voltage protection of the installations and devices but also the protection of persons against touch voltages.

Additionally the protection against high voltages becomes more and more important from an economic point of view, because of the increased use of electronic control and information systems. A paper of the Hamburger Hochbahn AG [6] explains that the damages which appear through overvoltage during a thunder storm or breaker operations have an increased negative economic effect due to the breaking down of the electronic and data transmission installations.

### 8.1 Protection of d.c. traction vehicles

From the very beginning it was standard and necessary to install surge arresters in d.c. traction vehicles. The first electrical traction vehicles had inductance coils as an overvoltage protection. Later horn arresters were additionally employed. Since the third decade of the last century arresters with non-linear resistors (SiC resistors in series with spark gaps) were used. Today, it is common to employ surge arresters without spark gaps directly at the current collector of the d.c. traction vehicle roof, as is to be seen in Figures 12 and 13. This protection concept is employed with the main-line railway and suburban service. The two-system locomotives (25 kV 50 Hz, 3 kV d.c.) also have surge arresters at the in-connector.

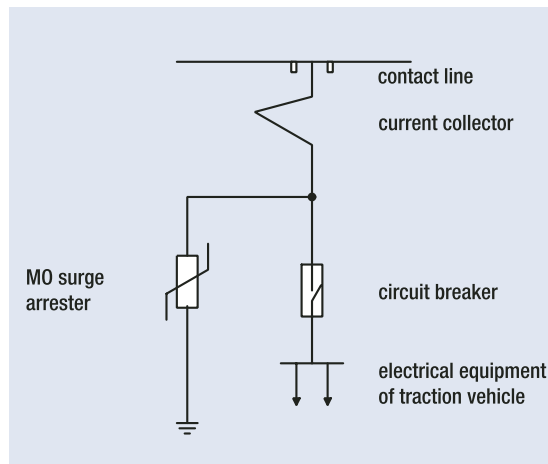


Figure 12: Arrangement of the surge arrester on the current collector of the traction vehicle.



Figure 13: Example of an arrester installation on a railway.

### 8.2 Dimensioning of the surge arresters

Exactly as with MO surge arresters of the a.c. railway networks, the continuous voltage  $U_c$  of the arrester should be set accordingly to the highest non-permanent voltage  $U_{\max 2}$ , that is

$$U_c \geq U_{\max 2}$$

#### 8.2.1 Urban traffic (< 1000 V)

According to table 3 the following standard values result: for networks with a nominal voltage of

$$U_n = 600 \text{ V follows } U_c \geq 800 \text{ V}$$

and

$$U_n = 750 \text{ V follows } U_c \geq 1000 \text{ V}$$

In both these situations, it is taken into account that in the case of regenerating braking, the values for  $U_{\max 2}$  can increase up to a maximum of 800 V ( $U_n = 600 \text{ V}$ ), and up to a maximum of 1000 V ( $U_n = 750 \text{ V}$ ), respectively.

For these networks the VDV paper 525 [7] recommends to employ surge arresters for outdoor use for the overhead contact system, at each distributing point, at the ends of the feeding sections, and at the coupling point as well as at power demand points (e.g. point heaters). For track sections with frequent lightning strokes, for instance on bridges or a free overland route, additional arresters are advisable. Feeding cables and the return wire in the transformer substation are also to be equipped with surge arresters. Figure 14 shows the protection concept. The arresters of the overhead line and the arresters A1 in the substation cause a reduction of the overvoltage to a harmless value in case of lightning strokes. The arrester A2 between return wire (rail) and the earth of the building should reduce the potential lifting of the rail. The arrester provides protection in case of direct lightning strokes in the railways, for instance for overhead tracks with current rails. The ABB arresters POLIM-H...ND, POLIM-H...SD and POLIM-R...ND prove to be suitable for all the above-mentioned applications, due to their high energy absorption capability, their low residual voltage (a good protection level  $U_{\text{res}}/U_c$ ) and a secure construction.

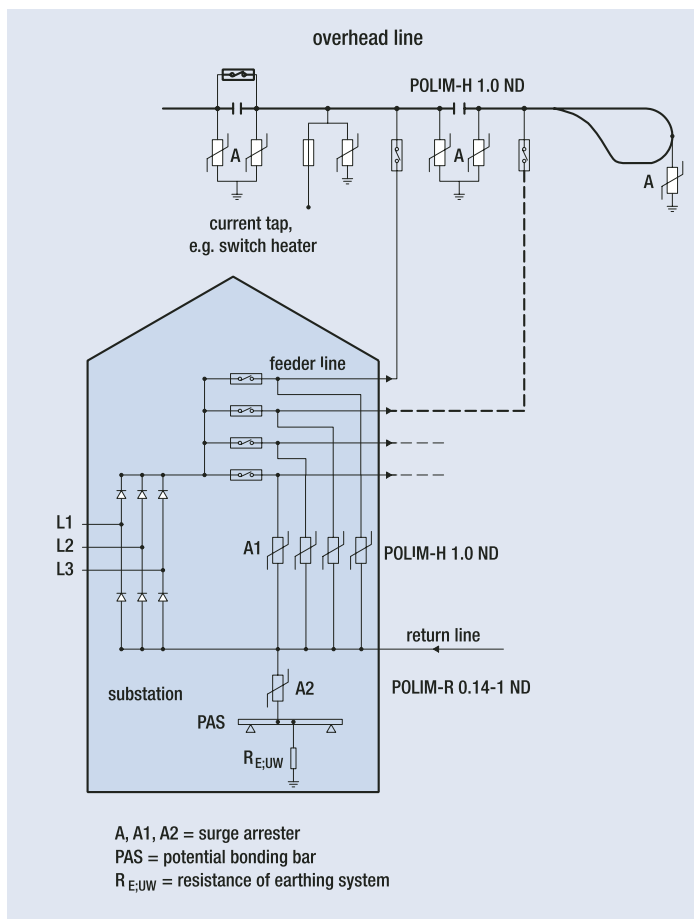


Figure 14: The protection of the traction current supply installation of a typical metropolitan railway ( $U_n = 750 \text{ V}$ ).

For traction vehicles and overhead lines (arrester A1) the POLIM-H 1,0 ND with  $U_c = 1$  kV and a residual voltage of  $U_{res} = 2,7$  kV (at  $I_n = 20$  kA) is recommended.

In the stations the POLIM-H 1,0 ND or the POLIM-H 1,0 SD can be used as A1-arrester. The POLIM-H 1,0 SD has the same electrical data as the POLIM-H 1,0 ND, it is mechanically weaker and has a smaller housing. Because of that it is suitable for installations that have little space.

Both arresters fulfil and exceed the required demands, and offer the best protection and security for traction current installations of d.c. railways.

The POLIM-R...ND is recommended as A2 arrester, because it has the same energy handling capability (POLIM-R...-1 ND), or even a higher one (POLIM-R...-2 ND) with a lowest  $U_{res}$ , compared to the POLIM-H...ND and POLIM H...SD. The arresters POLIM-H...ND, POLIM-H...SD and POLIM-R...-1 ND have active parts with the same diameter of the MO resistors of 75 mm, and are suited to one another both in current-voltage characteristic and in specific energy absorption. The arrester POLIM-R...-2 ND has as an active part two parallel connected MO resistors of a diameter of 75 mm, and offers an even better protection level by double energy absorption capability as the POLIM-R...-1 ND.

### 8.2.2 Long-distance traffic

According to Table 3 follows for the networks with a nominal voltage of

$$U_n = 1500 \text{ V a } U_c \geq 1950 \text{ V}$$

and

$$U_n = 3000 \text{ V a } U_c \geq 3900 \text{ V}$$

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

chosen. The arrester POLIM-H 4,2 ND with  $U_c = 4200$  V and  $U_{res} = 11,0$  kV is employed as a rule in networks with  $U_n = 3000$  V.

In regions that have strong thunder storms and use networks which have to absorb a very high energy in case of a fault condition, it is recommended to use the arrester POLIM-X...ND, which has the same continuous operating voltage as the POLIM-H...ND, but it can absorb twice as much energy.

In case that there are particular requirements, it is possible to work out together with the customer special solutions for the most favourable use of the arresters.

The Italian Railways use up to four arresters of the type POLIM-H 4,4 ND-S, which are parallel connected, in order to absorb the very high energy quantity. With the parallel connections it is important to take care of a very good current sharing among the arresters.

For the full trains in Russia ( $U_n = 3000$  V) a staggering concept was developed. In the substations, special fitted arresters of the type POLIM-H 4,0 ND (partially parallel connected) are used in order to absorb the very high energies which occur during short circuit disconnections at the lowest protection level. If necessary, arresters of a special fitted type of POLIM-H 4,5 ND are used on certain points of the track.

The arresters of the type POLIM-C 4,7 ND and POLIM-C 5,6 ND are used in the overhead line. This staggering of the residual stresses and the energy absorption capabilities secures that the overvoltages that occur can be limited and the currents can be directed to the earth at special places, which were chosen in advance. In this way a high protection level and a high availability of the energy supply are guaranteed. The described case was worked over in a close cooperation with the customer for adjusting the MO surge arresters to the especially hard requirements and for testing them accordingly.

## 9 | COMBINATION OF SURGE ARRESTERS AND LOW VOLTAGE LIMITERS

The requirements for the arresters A1 and A2 of d.c. railways with  $U_n = 750 \text{ V}$  and also  $U_n = 600 \text{ V}$  are specified in [7]. These requirements can be extended accordingly to d.c. railways with different nominal voltages. A1 and A2 arresters have to have the same voltage-current characteristic and the same specific energy absorption capability. That means as a rule that the diameters of the MO surge arresters have to be similar.

If the arresters have to be connected in parallel, as for instance in order to increase the energy absorption capability, it is necessary to share the current symmetrically between the arresters. In such cases it is necessary to consult the manufacturer in order to ask for current sharing measurements of the arresters which are intended to be connected in parallel.

Instead of an A2 arrester it is possible to use a low voltage limiter HVL. The MO resistors of the arrester POLIM-H have the same diameter and voltage-current characteristic as the HVL 120-0,3. The MO resistors of the arrester POLIM-X and of the HVL-ED 1 have a diameter of 108 mm each. The use of a low voltage limiter HVL instead of the arrester A2 ensures a better protection in any case.

Recently the thought came up to connect in parallel commercially available low voltage limiters and gapless MO surge arresters (A2 arresters), reaching with this a combination of the functions overvoltage protection and protection against unacceptable touch voltages with two separate devices. The solution would have the advantage that the A2 arrester protects the low voltage limiter against unwanted short circuiting due to lightning overvoltages.

Such a solution is in principle possible, but it has to be ensured that the characteristics of the two devices are matched one to the other, and that they are decoupled by an inductance.

Principle investigations show the problems [14], but also the possibilities for the development of a new device for protection against high potential differences.

Figure 15 shows an A2 arrester connected in parallel to a low voltage limiter (LVL). The breakthrough voltage of the LVL is  $U_s = 120 \text{ V}$ , the continuous voltage of the A2 arrester is  $U_c = 140 \text{ V d.c.}$  The arrangement was stressed with a lightning current impulse (wave shape 8/20  $\mu\text{s}$ ) of approximately 11 kA. It can be seen from the oscillogram that the whole current flows through the LVL, and that the current through the A2 arrester is almost zero. This is

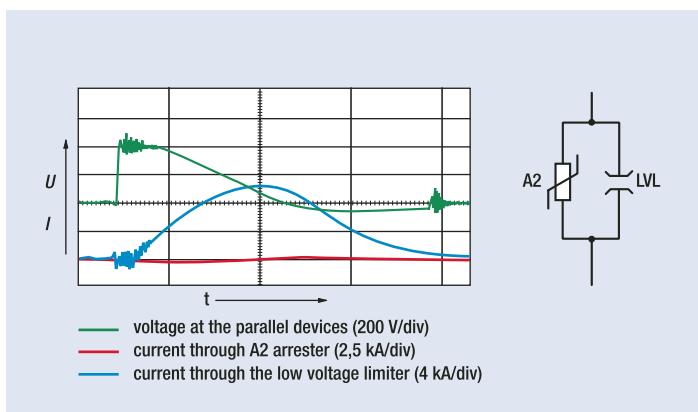


Figure 15: Current through and voltage at the parallel connection of an A2 arrester and a low voltage limiter (LVL).

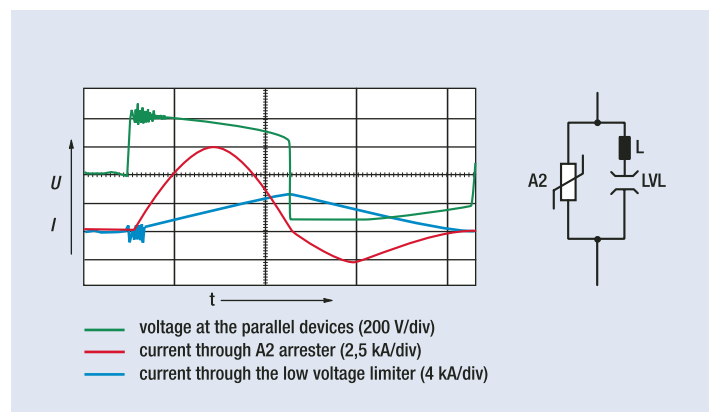


Figure 16: Current through and voltage at the parallel connection of an A2 arrester and a low voltage limiter (LVL) in series with an adapted inductance L.

## 10 | DIRECTIONS FOR INSTALLATION

due to the fact that the LVL goes in short circuit condition at a voltage level well below the clamping voltage of the A2 arrester. Therefore, this arrangement does not provide the desired function.

A well-adapted decoupling inductance in series to the LVL is needed to reach the desired work-together of the two separate devices, as shown in Figure 16.

The installed inductance causes a sufficient voltage rise, so that the A2 arrester starts conducting and takes over the larger part of the injected lightning current. The LVL is in this case protected by the A2 arrester against undesired short circuiting in case of a lightning stress. This combination provides both, the protection against too high touch voltages for persons and the protection of equipment against overvoltages. Undesired short circuits due to lightning overvoltages are prevented by the A2 arrester.

The described combination of an A2 arrester and a LVL with an adapted inductance, packed in a standard insulating housing, is produced and offered by the company ESN as potential protection device (Potenzialschutzeinrichtung).

In order to achieve the expected protection through the arrester it is to be taken into consideration that arresters have a limited local protection area. The voltages at the arrester terminals and those at the electrical equipment are not equally high because of the transient wave occurrences between the connection point of the arrester and the electrical equipment to be protected. The height of the voltage at the electrical equipment depends on the steepness of the overvoltage wave, its travelling speed along the line and also the distance between the arrester and the electrical equipment. Therefore, it is essential that the arrester is placed as close as possible to the electrical equipment to be protected. The connections at the high voltage side and the earth side must be as short and straight as possible. The earthing resistance must be low. A lower earthing resistance than  $10 \Omega$  is desirable as a standard value.

Additional directions as to assembly, installation, maintenance, transport, storage and disposal are to be found in the operating instructions.

## 11 | STANDARDIZATION

There is no international standard that covers all the arresters and the low voltage limiters for railway applications. IEC/EN 60099-4 is the standard for MO surge arresters without spark gaps in a.c. voltage networks. The arresters for a.c. voltage networks with a frequency of  $f = 16,7$  Hz and d.c. voltage applications are not covered. EN 50123-5 and IEC 61992-5 respectively cover the arresters and the low voltage limiters for fixed installations up to 3000 V d.c. The applications on rolling stock are not covered.

EN 50123-5 and IEC 61992-5 do not take into consideration the technological progress of the last few years and therefore can be used only partially for modern products. That is the reason why in CENELEC two technical committees (TC 37A and SC9XC) have working groups that are about to define a new standard for arresters and low voltage limiters in d.c. traction networks, respectively to review the existing EN 50123-5. These shall also contain rules for selection and application.

A publication about the arresters in railway facilities is worked out by the working group A3.17 of CIGRÉ.

## 12 | CONCLUSION

Lightning overvoltage and switching overvoltage are a risk for installations and equipment in electrical railways. MO surge arresters without spark gaps assure a reliable protection against inadmissible overvoltage stress. The ABB arresters with direct moulding of the silicon housing on the active part are particularly suitable for the application in railways, especially on traction vehicles, because of their high security in all operation cases.

The newly developed low voltage limiter of the type HVL ensures the protection of persons against inadmissible touch voltages.

During many discussions with the users of surge arresters and low voltage limiters it was noticed that a thorough information and co-operation is welcomed. Especially with the electrical railways it is very important because there are particular demands to be fulfilled, and with the modern MO surge arresters with silicon housing without spark gaps and the HVL new application possibilities may appear. With the newly developed products it is possible to find solutions for many special cases that didn't seem to be solvable until now.

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