APPLICATION GUIDELINES

Overvoltage protection in railway systems
Metal-oxide surge arresters and voltage limiting devices
Foreword

Since the first edition of the application guidelines from 2000, which describes the dimensioning, testing and use of metal-oxide arresters in rail systems, they have been very well received by our customers.

The further development of products, the enhancement of the portfolio and, in particular, the newly published standard for arresters and voltage limiting devices in DC rail systems have made it necessary to revise and expand the application guidelines.

This brochure provides a clear and succinct description of the most important technical principles and properties of metal-oxide surge arresters and voltage limiting devices as well as their use, testing and dimensioning for AC and DC rail systems.

We hope that you will benefit from the new, extended version of the brochure. We are very grateful for any additions, suggestions and technical information to improve this brochure.

Bernhard Doser
ABB Power Grids Switzerland AG
Wettingen, February 2020
# Table of contents

<table>
<thead>
<tr>
<th>Table of contents</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong> Introduction</td>
<td>6</td>
</tr>
<tr>
<td><strong>2</strong> Surge arresters</td>
<td>7</td>
</tr>
<tr>
<td>2.1 Overview</td>
<td>7</td>
</tr>
<tr>
<td>2.2 MO surge arresters</td>
<td>8</td>
</tr>
<tr>
<td>2.2.1 MO resistors</td>
<td>8</td>
</tr>
<tr>
<td>2.2.2 MO surge arrester construction</td>
<td>8</td>
</tr>
<tr>
<td>2.2.3 Silicone insulation</td>
<td>9</td>
</tr>
<tr>
<td>2.2.4 Normal operating conditions</td>
<td>9</td>
</tr>
<tr>
<td>2.2.5 Elevated ambient temperature</td>
<td>9</td>
</tr>
<tr>
<td>2.2.6 Altitude adjustment for arrester housing</td>
<td>10</td>
</tr>
<tr>
<td>2.2.7 Overload behavior, short circuit behavior</td>
<td>10</td>
</tr>
<tr>
<td>2.2.8 Mechanical stability</td>
<td>10</td>
</tr>
<tr>
<td>2.2.9 Pollution and cleaning</td>
<td>10</td>
</tr>
<tr>
<td>2.2.10 Flying sparks</td>
<td>10</td>
</tr>
<tr>
<td><strong>3</strong> Voltages in rail networks</td>
<td>12</td>
</tr>
<tr>
<td>3.1 Voltage definitions</td>
<td>12</td>
</tr>
<tr>
<td>3.2 Supply voltages of rail networks</td>
<td>13</td>
</tr>
<tr>
<td>3.2.1 Standardized parameters of DC and AC rail networks</td>
<td>13</td>
</tr>
<tr>
<td>3.2.2 Frequencies of AC rail networks</td>
<td>13</td>
</tr>
<tr>
<td>3.2.3 Nominal voltages for DC railways</td>
<td>13</td>
</tr>
<tr>
<td>3.2.4 Voltage fluctuations</td>
<td>14</td>
</tr>
<tr>
<td>3.3 Switching overvoltages</td>
<td>15</td>
</tr>
<tr>
<td>3.4 Touch voltages</td>
<td>16</td>
</tr>
<tr>
<td><strong>4</strong> Currents in rail networks</td>
<td>17</td>
</tr>
<tr>
<td>4.1 Traction currents</td>
<td>17</td>
</tr>
<tr>
<td>4.2 Fault currents</td>
<td>17</td>
</tr>
<tr>
<td>4.3 Stray currents</td>
<td>17</td>
</tr>
<tr>
<td><strong>5</strong> Lightning currents and overvoltages</td>
<td>18</td>
</tr>
<tr>
<td><strong>6</strong> Arresters for AC rail networks</td>
<td>20</td>
</tr>
<tr>
<td>6.1 Applicable standards</td>
<td>20</td>
</tr>
<tr>
<td>6.2 Definitions of important arrester parameters</td>
<td>20</td>
</tr>
<tr>
<td>6.3 Technical data of ABB arresters for AC rail systems</td>
<td>20</td>
</tr>
<tr>
<td>6.4 Type tests in accordance with IEC/EN 60099-4</td>
<td>20</td>
</tr>
<tr>
<td>6.5 Railway-specific special tests</td>
<td>21</td>
</tr>
<tr>
<td>6.5.1 Vibration and shock tests</td>
<td>21</td>
</tr>
<tr>
<td>6.5.2 Wind tunnel tests for high-speed trains</td>
<td>21</td>
</tr>
<tr>
<td>6.5.3 Fire behavior test</td>
<td>21</td>
</tr>
<tr>
<td>6.6 Final and acceptance tests</td>
<td>21</td>
</tr>
<tr>
<td>Chapter</td>
<td>Title</td>
</tr>
<tr>
<td>---------</td>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>7</td>
<td>Overvoltage protection in AC rail networks</td>
</tr>
<tr>
<td>7.1</td>
<td>Overvoltage protection in railway power supply</td>
</tr>
<tr>
<td>7.2</td>
<td>Surge protection of rail systems and locomotives</td>
</tr>
<tr>
<td>7.2.1</td>
<td>Arrester selection in the 25kV/50Hz AC network</td>
</tr>
<tr>
<td>7.2.2</td>
<td>Arrester selection in the 15kV/16.7Hz AC network</td>
</tr>
<tr>
<td>8</td>
<td>Arresters for DC rail networks</td>
</tr>
<tr>
<td>8.1</td>
<td>Applicable standards</td>
</tr>
<tr>
<td>8.2</td>
<td>Definitions of important arrester parameters</td>
</tr>
<tr>
<td>8.3</td>
<td>Technical data of ABB arresters</td>
</tr>
<tr>
<td>8.4</td>
<td>Type tests in accordance with EN 50526-1 and IEC 62848-1</td>
</tr>
<tr>
<td>8.5</td>
<td>Railway-specific special tests</td>
</tr>
<tr>
<td>8.5.1</td>
<td>Vibration and shock tests</td>
</tr>
<tr>
<td>8.5.2</td>
<td>Wind tunnel tests for high-speed trains</td>
</tr>
<tr>
<td>8.5.3</td>
<td>Fire behavior test</td>
</tr>
<tr>
<td>8.6</td>
<td>Final and acceptance tests</td>
</tr>
<tr>
<td>9</td>
<td>Overvoltage protection in DC rail networks</td>
</tr>
<tr>
<td>9.1</td>
<td>Overvoltage protection in railway power supply</td>
</tr>
<tr>
<td>9.2</td>
<td>Overvoltage protection of DC rail networks</td>
</tr>
<tr>
<td>9.3</td>
<td>Surge protection of DC traction vehicles</td>
</tr>
<tr>
<td>9.4</td>
<td>Selection of arresters in urban traffic</td>
</tr>
<tr>
<td>9.5</td>
<td>Selection of arresters in long-distance traffic</td>
</tr>
<tr>
<td>10</td>
<td>Voltage limiting devices</td>
</tr>
<tr>
<td>10.1</td>
<td>Introduction</td>
</tr>
<tr>
<td>10.2</td>
<td>Definitions according to EN 50122-1</td>
</tr>
<tr>
<td>10.3</td>
<td>Classification according to IEC 50526-2</td>
</tr>
<tr>
<td>10.4</td>
<td>Structure and function of HVL voltage limiters</td>
</tr>
<tr>
<td>10.5</td>
<td>Definitions of important parameters</td>
</tr>
<tr>
<td>10.6</td>
<td>Voltage limiting device technical data</td>
</tr>
<tr>
<td>10.7</td>
<td>Type tests in accordance with EN 50526-2</td>
</tr>
<tr>
<td>10.8</td>
<td>Final and acceptance tests</td>
</tr>
<tr>
<td>10.9</td>
<td>Use of voltage limited devices</td>
</tr>
<tr>
<td>11</td>
<td>Installation directions</td>
</tr>
<tr>
<td>12</td>
<td>Conclusion</td>
</tr>
<tr>
<td>13</td>
<td>Bibliography</td>
</tr>
</tbody>
</table>
1 Introduction

More and more people are settling in big cities. In order to ensure the mobility of these people and the transport of goods within and between such metropolises, increasingly efficient public transport systems are necessary. Huge investments are required in local and long-distance transport for people and goods.

Increasing frequency of trains as well as very high reliability and availability of trains and infrastructure are paramount to this.

To achieve this, overvoltage protection in the electrical power supply of rail systems and on the rolling stock must also be given the necessary attention. This applies both to AC rail systems and to long-distance and local DC rail systems.

The use and dimensioning of metal-oxide surge arresters (MO arresters) with no spark gaps in railway system mains with 50 Hz and 16.7 Hz AC voltage does not differ significantly from that of general energy supply, for which there have been proven standards for years.

However, the situation with DC-powered railway systems was unsatisfactory because there was no standard adapted to the specific conditions. Since 2012, there has been a new standard for the dimensioning and testing of MO arresters in DC rail systems, which is referred to in this application guideline.

Overvoltages in electrical supply networks are caused by lightning and switching operations and cannot be avoided. They endanger the operating equipment because their dielectric strength cannot be designed as high as required for economic reasons. Economical and reliable network operation therefore requires adequate protection of the operating equipment insulation against impermissible voltage stress. This generally applies to all electrical power supply networks.

The different types of overvoltages and the possibilities for limitation are only briefly discussed here. For general considerations, please see our application guidelines for the use of MO arresters in medium-voltage networks [1] and the further literature referenced therein. It should be mentioned here that lightning surges represent the greatest threat to devices in rail networks. The overvoltage protection must be designed to limit these surges to a value that is safe for the device insulation. MO arresters with no spark gaps are ideally suited for this. Technically outdated protective devices such as arcing horns and spark gap-based arresters or arresters in porcelain housing are no longer discussed.

In some applications, for example overland routes with a high risk of lightning or on exposed bridges, the MO arresters on the railway supply line and on rolling stock may be subjected to high levels of energy when a close or direct strike onto the overhead line occurs. ABB’s broad product portfolio of railway arresters with different energy classes offers solutions for all applications.

To avoid stray current corrosion, the tracks on DC trains are usually laid insulated. This may lead to inadmissibly high touch voltages and thus to danger to persons in the event of faults, for example in the event of an overhead line break, but also in certain operating cases. Voltage limiting devices of the HVL type protect people from these dangerous touch voltages.

In 2014, a new standard for voltage limiting devices appeared, which is also referred to in this application guideline.
2 Surge arresters

Until the mid-1980s, so-called “conventional” arresters were used almost exclusively in electrical power supply systems. They consist of a series connection of SiC resistors and spark gaps that are built into porcelain housing and are referred to as “spark gap arresters”.

2.1 Overview
Spark gap arresters in porcelain housing have several disadvantages: They only limit the overvoltages that are higher than the ignition voltage of the spark gaps. The response voltage increases with the front steepness of the incoming voltage wave. In other words, in the case of very steep pulses, these arresters do not offer sufficient overvoltage protection.

If the outer insulation of the porcelain housing is heavily polluted, the housing may flash over. Thanks to the hydrophobic nature of the silicone, MO arresters with silicone housing offer better pollution behavior.

If several spark gap arresters are connected in parallel (e.g. arresters in the railway supply line and arresters on the rolling stock), only one arrester ignites when a transient surge occurs, namely the one with the lowest response voltage. This then limits the overvoltage to a value below the ignition voltage of the other arresters, which prevents their response. It is therefore not generally possible for spark gap arresters to distribute the occurring energy to several arresters.

In the case of spark gap arresters, a follow current flows after the response and the limitation of the overvoltage until it is switched off or until zero-current transition. In contrast, an MO arrester only carries the current for the short duration of the surge. In other words, a spark gap arrester absorbs significantly more energy during a discharge process than an MO arrester. In addition, the energy absorption capacity of an MO arrester can be increased further by selecting an MO resistor with a larger diameter.

With spark gap arresters, the follow current flows three times longer at 16.7 Hz than at 50 Hz, which overloads the spark gap arrester with the same voltage design. In the past, this led to spark gap arresters for use in networks with 16.7 Hz having an unfavorably higher response voltage than arresters for 50 Hz - and thus a poorer level of protection.

When using spark gap arresters in DC voltage networks, there is always the problem of extinguishing an arc caused by the overvoltage.
If an arrester with porcelain housing is overloaded, there is always the risk that the porcelain insulator will burst and falling porcelain parts may pose a risk to people and equipment.

Since they are not protected by insulating housing, arcing horns have the disadvantage that their function heavily depends on the condition and the ambient conditions (electrode erosion, moisture, ice, dirt, foreign bodies, animals, etc.). The ignition voltage has a large scatter. After ignition, a short circuit current flows between the arcing horns. In contrast to this, the follow current in arresters is limited by the built-in resistors. It is also to be expected that an ignited arc in a DC voltage network will not extinguish and will burn until the voltage is switched off since there is no natural zero-current crossing.
2.2 MO surge arresters
Two significant improvements to spark gap arresters have resulted in the arrester technology we use today. On the one hand, the series connection of spark gaps and SiC resistors was replaced by metal-oxide resistors (MO resistors), and on the other hand, the previously used porcelain housing was replaced by polymer material.

The requirements and tests of IEC/EN 60099-4 [2] apply to MO surge arresters with no spark gaps which are used in AC systems and for MO surge arresters without spark gaps used in DC voltage networks, the requirements and tests of EN 50526-1/IEC 62848-1 [3, 4] are valid. The MO surge arresters by ABB were developed and type-tested in accordance with these standards and meet their requirements.

2.2.1 MO resistors
MO resistors make up the active part of the MO surge arrester. They are made of different metal-oxide powders which are compressed and sintered into round blocks [5].

ABB in Switzerland manufactures MO resistors for DC and AC applications with a wide range of diameters and heights. The diameter of the MO resistors increases the charge and energy absorption capacity of the arresters in which these MO resistors are used. The operating voltage increases with the height of the MO resistors or MO resistor stack in the MO surge arrester. The energy absorption capacity of the MO surge arrester is proportional to the volume of the installed MO resistors.

The edges of the MO resistors are metalized with aluminum and form the contact areas. The housing is coated with glass and encapsulates the ceramic covering, see Figure 1.

2.2.2 MO surge arrester construction
The patented principle of construction of the ABB arresters with silicone direct-molding consists of two electrodes which are connected to one another through two or more glass fiber-reinforced elements. This results in a hard cage, 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, thus forming the active part, which is completely encapsulated with silicone. The result is a completely sealed and compact surge arrester without any air gaps or voids inside. Figure 2 shows a POLIM-H type surge arrester constructed using this technique before and after silicone molding. The extremely flexible, modular design allows the arrester to be adapted to the desired requirements.
2.2.3 Silicone insulation
Silicone is an excellent insulation material for high-voltage applications. The advantageous properties of silicone for the insulation of MO surge arresters are:
• Resistance to contamination due to the hydrophobicity of the material
• High mechanical tear resistance
• Elastic material
• Meets very high fire protection requirements
• Low weight
• UV resistance
• Self-extinguishing

In the course of the development of the MO arrester with silicone encapsulation, long-term tests over several years were carried out as part of a research project at the Technical University of Tampere in Finland. During the test period, the test specimens were under voltage in a test chamber with very high humidity at a temperature of over 30 °C. In these tests, our arrester design with silicone direct-molding proved its worth.

2.2.4 Normal operating conditions
If the arresters are correctly selected according to the system voltages and the expected electrical and mechanical loads, a service life of more than 40 years can be expected under normal operating conditions.

In accordance with the standards, the normal operating conditions for MO arresters in rail systems are defined as follows:
• Ambient temperature −40 °C to +40 °C
• Solar radiation 1.1 kW/m²
• Installation altitude up to 2000 m above sea level
• Frequency of the AC voltage: 50 Hz, 60 Hz, 16.7 Hz
• Wind speed ≤34 m/s (122 km/h) or 32 m/s (115 km/h)

All ABB arresters meet or exceed the requirements of these operating conditions.

Some special cases are explained below.

2.2.5 Elevated ambient temperature
ABB arresters (AC and DC voltage) are guaranteed to function flawlessly up to 40 °C ambient temperature. This also includes the maximum solar radiation of 1.1 kW/m² for outdoor arresters. If there are heat sources in the vicinity of the arrester, the higher ambient temperature must be taken into account, and the value of $U_c$ increased if necessary. If the ambient temperature exceeds 40 °C, the continuous voltage $U_c$ must be increased by 2% for every 5K of temperature. This correction is possible up to a maximum ambient temperature of 80 °C.

To check the behavior at extremely low temperatures, cold tests were carried out in air down to -60 °C and icing tests successfully passed at temperatures down to -40 °C.
2.2.6 Altitude adjustment for arrester housing
The ABB arresters can be used without any housing adjustment in DC systems up to an altitude of 1,800 m above sea level. At higher altitudes, the air density may be so low that the withstand voltage of the arrester housing (external flashover) is no longer sufficient. In this case, the same MO resistor or MO resistor stack (same level of protection) is installed in extended housing with a correspondingly longer flashover distance.

As a guideline, one can assume that at an altitude of more than 1800 m above sea level, the flashover distance of the arrester housing must be increased by 10% per 1000 m altitude. For example, at an altitude of 3,300 m above sea level, the flashover distance of the housing must be 15% longer than that of a standard model.

The flashover distances of arresters for the lower voltages are relatively large from the outset, and usually far exceed the minimum requirements for the insulation withstand voltage. It is therefore advisable to check on a case-by-case basis whether the standard housing already has a sufficient flashover distance for use at higher altitudes.

2.2.7 Overload behavior, short circuit behavior
Any arrester can be overloaded in operation. The causes might be an extremely high lightning current or a so-called voltage transfer. This is understood as a short circuit between two different voltage levels, e.g. if a conductor line breaks and falls on an overhead line with a lower voltage. In such a case, the arrester is energetically overloaded. As a result of the overload, the MO resistors become so hot that they either spark over or break down and usually form a permanent short circuit. An arc results inside the arrester and its current is defined by the short circuit power of the network. With the ABB arresters with silicone housing there is no danger of “violent scattering” in case of an overload. There are no air gaps between the active part of the arrester and its silicone insulation for pressure to build up. The hot arc quickly escapes through the silicone insulation and burns freely on the outside. In the short-circuit type test, the behavior of the arrester after such an overload is checked for the specified currents and the conformity to standards is verified.

2.2.8 Mechanical stability
The arresters recommended by ABB for rail applications are extremely mechanically robust. They are even reliable in areas with high earthquake activity. Please observe the permissible mechanical loads as specified in the data sheets. Arresters for use on rail cars are vibration- and shock-tested in accordance with IEC 61373 [6] and are available with a reinforced base plate.

2.2.9 Pollution and cleaning
Silicone is the best insulation material against pollution. This is especially because the material is water-repellent (hydrophobic) [7]. An arrester with silicone insulation behaves more favorably under conditions of heavy pollution than an arrester with porcelain housing or housing made of another polymer insulating material.

In cases of heavy pollution, the hydrophobicity may be lost during operation. The decisive factor in assessing the long-term behavior of plastic insulation is whether this loss is permanent or temporary. In contrast to other plastics, silicone elastomers are able to regain hydrophobicity after loss.

Heavily polluted arresters on trains can be cleaned with water or isopropanol. Please see the operating instructions for the relevant arrester types.

2.2.10 Flying sparks
The silicone used in ABB arresters is a flame-retardant and self-extinguishing material. Tests have shown that hot or glowing particles, which emerge when the pantographs jump or when braking, do not adversely affect the silicone housing of the arrester. There is no risk that the arrester will be ignited by sparks or that the insulation capacity of the housing will be reduced by deposited particles in the event of humidity or rain.
All metal-oxide resistors in the ABB railway arresters are from our own production with full control of all manufacturing steps for the highest quality standards.
3 Voltages in rail networks

3.1 Voltage definitions

The European standard EN 50163 [8] and the international standard IEC 60850 [9] define the operating voltages for railway applications. The permissible overvoltages and undervoltages are also specified in these standards.

In the following, some definitions and voltage values that are important for insulation coordination and overvoltage protection are given and briefly explained.

Voltage $U$
Potential difference between overhead contact line and return line or earth.

Nominal voltage $U_n$
The value specified for a system.

Highest permanent voltage $U_{\text{max}1}$
The maximum value of voltage that can occur for an indefinite period.

Highest non-permanent voltage $U_{\text{max}2}$
The maximum value of voltage that can occur for a limited period of time.

Overvoltage
Any voltage that has a peak that exceeds the peak of the highest non-permanent voltage $U_{\text{max}2}$ under normal operating conditions.

Long-term overvoltage
Overvoltage that is higher than $U_{\text{max}2}$ and typically lasts longer than 20 ms, for example as a result of a voltage rise on the primary side of substations.

Highest long-term overvoltage $U_{\text{max}3}$
Voltage that is defined as the highest value of the long-term overvoltage for a period of 20 ms. This value is independent of frequency.

Switching surge
Transient overvoltage at any point in the system caused by a typical switching operation or fault condition in the network.

Lightning surge
Transient overvoltage at any point in the system caused by a typical lightning discharge.
3.2 Supply voltages of rail networks

3.2.1 Standardized parameters of DC and AC rail networks

Table 1 shows the characteristic parameters for the main supply voltages for AC and DC rail networks. Figure 3 shows a schematic representation of the maximum values of the voltages occurring in these networks depending on the duration.

3.2.2 Frequencies of AC rail networks

The nominal value of the frequency in the 15kV network is 16.7 Hz. The nominal value of the frequency in the 25kV network is 50 Hz. In some countries, the frequency of the rail network has a nominal value of 60 Hz.

3.2.3 Nominal voltages for DC railways

In addition to the preferential voltages 750 V, 1500 V and 3000 V specified in Table 1 there are some other voltages in use for DC railways. Table 2 shows the common DC voltage levels and their areas of application.

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### Table 1: Characteristic parameters for the main supply voltages for AC and DC rail networks.

<table>
<thead>
<tr>
<th>Power supply system</th>
<th>Nominal voltage ( U_n ) V</th>
<th>Highest permanent voltage ( U_{\text{max1}} ) V</th>
<th>Highest non-permanent voltage ( U_{\text{max2}} ) V</th>
<th>Highest long-term overvoltage ( U_{\text{max3}*} ) V</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC voltage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(average values)</td>
<td>750</td>
<td>900</td>
<td>1000</td>
<td>1270</td>
</tr>
<tr>
<td></td>
<td>1500</td>
<td>1800</td>
<td>1950</td>
<td>2250</td>
</tr>
<tr>
<td></td>
<td>3000</td>
<td>3600</td>
<td>3900</td>
<td>5075</td>
</tr>
<tr>
<td>AC voltage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(effective values)</td>
<td>15000</td>
<td>17250</td>
<td>18000</td>
<td>24300</td>
</tr>
<tr>
<td></td>
<td>25000</td>
<td>27500</td>
<td>29000</td>
<td>38750</td>
</tr>
</tbody>
</table>

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

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### Table 2: Nominal voltages of DC railways and their areas of application.

<table>
<thead>
<tr>
<th>Train type</th>
<th>Nominal voltage</th>
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<tbody>
<tr>
<td>Mine railways underground</td>
<td>220 V and 500 V</td>
</tr>
<tr>
<td>Mine railways overground</td>
<td>1200 V, 1500 V, 2400 V, 3000 V</td>
</tr>
<tr>
<td>Trams, trolley bus</td>
<td>600 V and 750 V</td>
</tr>
<tr>
<td>Underground/suburban railway</td>
<td>750 V, 1200 V, 1500 V and 3000 V</td>
</tr>
<tr>
<td>Commuter railway</td>
<td>750 V to 3000 V</td>
</tr>
<tr>
<td>Long-distance railway</td>
<td>1500 V and 3000 V</td>
</tr>
</tbody>
</table>
3.2.4 Voltage fluctuations

The voltages in rail networks are subject to considerable fluctuations. Figure 4 shows an example of the measured voltage $U$ at the pantograph of a modern DC local train in undisturbed operation during a 25-minute test run. The voltage curve at the pantograph is not only influenced by the power requirements of the respective vehicle itself, but also by other vehicles in the network and their position to the supplying substation. The illustrated short-time voltage peaks appear, for instance, when passing an isolator, jumping the pantograph, switching, or at the beginning of the braking process through the converter. Figure 5 shows another example of the voltage curve $U$ at the pantograph during a tram test run.

Vollenwyder [10] describes another example of the variation of operating voltage in a 25kV/50Hz rail network as a result of harmonics. Figure 6 shows strong harmonics caused by the single-phase control of a high-speed train. Despite the setting of the fundamental voltage amplitude below the usual value of 27.5 kV$_{\text{eff}}$, a voltage peak of 55 kV was measured for the harmonics.
3.3 Switching overvoltages

Overvoltages are generated during switching. The level and duration of these overvoltages depend on the type of breakers used. Special attention is paid to breakers in DC networks. Because there is no zero-current crossing, the DC voltage breakers differ significantly from the switch types with insulating gas or vacuum interrupters, which are used in AC networks. DC voltage breakers are either mechanical switching devices with many arcing chambers and air as an insulating medium, or semiconductor or hybrid switches, consisting of a semiconductor switch and a mechanical switching device. The switching overvoltages of a DC voltage switch can reach four times the nominal voltage \[11\]. The switching times differ depending on the breaker design. **Figure 7** shows the typical course of voltage and current when switching off a short circuit at the end of the 3kV line with a mechanical DC breaker.

The switching overvoltage across the terminals of the surge arrester can reach three times the nominal voltage. The surge arrester was selected so that it does not yet significantly limit this surge. It only absorbs low energy during switching operations in the rail network.
3.4 Touch voltages
Besides the protection of the devices and installations against overvoltages, which are caused by lightning discharges and switching, it is also very important to take into consideration the protection of persons against inadmissibly high touch voltages in operation and under fault conditions.

The following definitions are specified in EN 50122-1 [12]:

**Touch voltage**
Voltage between conductive parts when touched simultaneously by a person or an animal.

This standard specifies the maximum permissible touch voltages $U_{te, \text{max}}$ for DC and AC rail systems as a function of time duration.

**Figure 8** shows the time dependence of the maximum permissible touch voltages $U_{te, \text{max}}$ for DC traction systems.

Area ① defines the maximum permissible touch voltage $U_{te, \text{max}}$ for short-term events, e.g. in case of faults. The permitted voltage lies between 870 V for $t = 0.02 \text{ s}$ and 350 V for an exposure duration of $t < 0.7 \text{ s}$.

The standard does not specify any limit values for the time range $t < 0.02 \text{ s}$, which applies to transient events such as lightning strikes or switching.

Area ② defines the maximum permissible touch voltage $U_{te, \text{max}}$ for long-term events, e.g. in operational cases. The permitted voltage lies between 175 V for $t = 0.7 \text{ s}$ and 120 V for an exposure duration of $t < 300 \text{ s}$.

In workshops and similar locations, the touch voltages must not exceed 60 V during operation.

**Figure 9** shows the time dependence of the maximum permissible touch voltages $U_{te, \text{max}}$ for AC traction systems.

Area ① defines the maximum permissible touch voltage $U_{te, \text{max}}$ for short-term events, e.g. in case of faults. The permitted voltage lies between 865 V for $t = 0.02 \text{ s}$ and 155 V for an exposure duration of $t < 0.7 \text{ s}$.

The standard does not specify any limit values for the time range $t < 0.02 \text{ s}$, which applies to transient processes such as lightning strikes or switching.

Area ② defines the maximum permissible touch voltage $U_{te, \text{max}}$ for long-term events, e.g. in operational cases. The permitted voltage lies between 90 V for $t = 0.7 \text{ s}$ and 60 V for an exposure duration of $t < 300 \text{ s}$.

In workshops and similar locations, the touch voltages must not exceed 25 V during operation.
4 Currents in rail networks

4.1 Traction currents
Given the relatively low voltages of the DC trains, the currents required for these areas of application (in the order of 500 kW for trams, 1500 kW for suburban railways) generate considerable currents. The starting currents of modern trams reach values up to 1700 A, traction vehicles in the 3000V network and subways have starting currents of 4000 A. The currents in AC trains are lower, comparable to the currents that occur in networks of electric supply companies.

4.2 Fault currents
In case of shorts to earth or short circuits it is possible that electrical currents from some 100 A up to 50 kA can flow in rail networks, depending on the distance between failure and supply station.

Short circuits often occur in overhead contact line systems on railways compared to the state energy supply. Three short circuits can be expected for long-distance railways per year and route kilometer. The frequency of short circuits is generally higher for short-distance trains. The main causes of the short circuits include:

- Travel of electric traction vehicles in earthed sections
- Flashover of insulators, for instance due to contamination or lightning strike
- Damage from the exterior, such as trees or branches after storms, accidents with construction cranes, accidents with vehicles at level crossings, vandalism
- Damage to pantographs, traction vehicles or in the contact line system

4.3 Stray currents
A special problem with the operation of DC trains is stray current corrosion. With DC trains 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 ground to the rectifier substation. If there are buried metal installations inside the area of influence of the railway, for instance pipes or cable coverings, a part of the reverse current also flows through these buried metal devices. Electrochemical corrosion occurs at the points of exit of the current from the metal, in which the ground acts as an electrolyte. For example, from a constantly flowing current of just one ampere, 9.1 kg of iron, 10.4 kg of copper and 33.4 kg of lead are removed in the course of a year.

These negative influences become more important the higher the transmission power required. The tracks of DC trains are therefore laid insulated in order to reduce these influences. However, this has the consequence that the rail potential can rise and thus inadmissibly high touch voltages can occur.

Stray current corrosion is not an issue on AC rail systems. The rails in these systems are earthed.
5 Lightning currents and overvoltages

The lightning parameters are derived from statistical analyses of worldwide lightning measurements [13]. The most frequently occurring negative cloud-to-ground lightning strikes 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 μs
- Time to half value: 75 μs

The charge applied to the overhead line in the event of a direct lightning strike spreads in the form of two transient current waves in both directions from the point of impact. The transient voltage waves are linked to the current waves via the surge impedance of the line. The surge impedances of the overhead lines of DC and AC rail systems are typically between 380 Ω and 460 Ω. A surge impedance of approx. 160 Ω can be expected for bus bars.

If one takes the peak value of the lightning of 30 kA assumed above, transient waves occur with a peak value of 15 kA each which, with a surge impedance of e.g. 400 Ω, result in an overvoltage of 6000 kV with a voltage steepness of approx. 1000 kV/μs. If this overvoltage wave reaches the next insulator, a flashover occurs, whereby the level of the overvoltage on the line is limited to the flashover voltage of the insulator.

The minimum dielectric strength $U_{\text{Ni}}$ of the equipment, including the insulators in the event of lightning surge depends on the system voltage and the hazard category; the setpoints are defined in EN 50124-1 [14]. The equipment in the DC and AC rail networks must be protected against transient overvoltages using surge arresters in accordance with the rules of insulation coordination.

In standards and for testing and coordination purposes, the standard lightning current impulse for surge arresters (IEC 60060-1) [15] with an amplitude of 10 kA or 20 kA and a rise time of 8 μs and a time to half-value on the tail of 20 μs (waveform 8/20 μs) is used. This waveform is comparable to an incoming lightning shock wave after flashover on an isolator.

Furthermore, the high current impulse with the waveform 4/10 μs and peak values up to 200 kA as well as the switching surge current with the waveform 30/60 μs and peak values up to 2 kA are standardized.

To test lightning protection devices and so-called lightning arresters in lightning protection technology, a lightning current with the waveform 10/350 μs is used.

The ABB metal-oxide surge arresters were specially developed and type-tested in accordance with the latest international standards for rail applications.
6 Arresters for AC rail networks

6.1 Applicable standards
In general, the same standards apply to MO arresters in AC rail systems as for arresters in general energy supply networks. For this reason, these arresters are specified and type-tested in accordance with IEC/EN 60099-4. Additional requirements apply to MO arresters that are mounted on rail vehicles.

6.2 Definitions of important arrester parameters

Continuous operating voltage $U_c$
The highest permissible effective value of the operating frequency AC voltage, which may be continuously applied to the arrester terminals.

Rated voltage $U_r$
The highest permissible effective value of an operating frequency overvoltage applied to the arrester terminals for 10 sec., as specified in the operating duty test.

Nominal discharge current of an arrester $I_n$
The peak value of the lightning current impulse, which is used to classify the surge arrester as per IEC/EN 60099-4.

Residual voltage $U_{res}$
Peak value of the voltage at the arrester terminals when a surge current of defined amplitude and waveform flows.

Lightning impulse protection level $U_{pl}$
Maximum residual voltage of an arrester at the nominal discharge current. The ratio $U_{pl}/U_c$ indicates the protection level of a surge arrester. The smaller the ratio, the lower the arrester limits the overvoltage and thus better protects the device insulation.

Repetitive charge transfer rating $Q_{rs}$
Specified maximum charge transfer capacity of an arrester, which it can conduct several times without causing mechanical or unacceptable electrical aging. The test sequence is defined in IEC/EN 60099-4.

Thermal energy rating $W_{th}$
Specified maximum energy in kJ/kV that may be injected into an arrester without causing a thermal runaway. The test sequence is defined in IEC/EN 60099-4.

6.3 Technical data of ABB arresters for AC rail systems
The requirements for the arresters depend on the operating conditions and type of equipment to be protected. ABB offers a range of different arrester types that cover all possible requirements. All arresters focus on the reliability and durability of the products.

Important data regarding the arresters recommended for use in AC rail networks are summarized in Table 3.

Further information on the properties of these products can be found in the data sheets at www.abb.com/arrestersonline.

6.4 Type tests in accordance with IEC/EN 60099-4
Type tests are tests which are carried out once to demonstrate that a special arrester type operates properly under the loads defined in the standard. The following type tests are to be carried out on the ABB arresters:

- Insulation withstand test on the arrester housing, in other words the voltage withstand strength of the outer insulation
- Testing the residual voltage of the MO resistors at various current pulses and waveforms, i.e. the protection characteristics with steep current impulse, lighting current impulse and switching current impulse
- Testing the repetitive charge transfer withstand capacity of the MO resistors with rectangular surge currents
- Operating duty test on thermal arrester models, i.e. verification of the thermal energy absorption capacity
- Mechanical tests and tightness testing
- Evidence of pressure relief in the event of a short circuit, in other words, the behavior when overloaded
- Contamination test over 1000h in salt spray chamber and UV testing on the insulating material.
- Test to prove long-term stability under normal conditions (aging test)
6.5 Railway-specific special tests

6.5.1 Vibration and shock tests
If MO arresters are used on locomotives or other rolling stock, they are exposed to constant vibrations and occasionally shock loads. The ABB MO arresters recommended for this application have been successfully tested for shock and vibration in accordance with IEC 61373. These arresters are mounted with reinforced base plates.

6.5.2 Wind tunnel tests for high-speed trains
When installing the MO arrester on high-speed trains, they are exposed to high wind speeds, which can cause the sheds of the silicone insulation to resonate. There is also a risk that the high wind pressures will push the sheds down and thus reduce the flashover and creepage distances. The ABB MO arresters recommended for this application have been successfully tested in the wind tunnel of the German Aerospace Center (DLR) up to a speed of 360 km/h [16] and are suitable for use on high-speed trains.

6.5.3 Fire behavior test
Extensive evidence of fire behavior is required for use in railways. The silicone elastomers used to isolate ABB MO arresters have been tested in accordance with various test standards, including for flue gas development, optical density of the flue gases, composition of the flue gases and oxygen content, and comply with EN 45545-2 [17] among other standards. The silicones used meet hazard level HL2 and partly HL3 for the requirements R22 (indoor use) and R23 (outdoor use).

6.6 Final and acceptance tests
All arresters are individually tested in accordance with IEC/EN 60099-4. As part of the final test, the reference voltage and the leakage current at the continuous voltage $U_c$ are determined as well as the freedom from PD. For arresters for use in railway system mains with 16.7 Hz, the routine tests are usually carried out with equivalent 50 Hz voltages and currents.

Acceptance tests must always be agreed between the manufacturer and the purchaser.

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Table 3: ABB arresters for AC rail systems

<table>
<thead>
<tr>
<th></th>
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<td>Station SM</td>
<td>Station SL</td>
<td>Station SL</td>
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<td>≤7.5 kV</td>
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<td>10 kA</td>
<td>10 kA</td>
<td>10 kA</td>
<td>10 / 20 kA</td>
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<td>2.0 As (C)</td>
<td>1.6 As (C)</td>
<td>1.0 As (C)</td>
<td>1.6 As (C)</td>
<td>2.5 / 5.0 As (C)</td>
</tr>
<tr>
<td>Thermal energy rating $W_{th}$</td>
<td>15 kJ/kV ($U_c$)</td>
<td>10 kJ/kV ($U_c$)</td>
<td>6.25 kJ/kV ($U_c$)</td>
<td>5.6 kJ/kV ($U_c$)</td>
<td>6.25 kJ/kV ($U_c$)</td>
<td>12 kJ/kV ($U_c$) / 24 kJ/kV ($U_c$)</td>
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<td>Equipment of secondary technology</td>
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<td></td>
<td></td>
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</tr>
</tbody>
</table>

x Main types, recommended according to required energy absorption capacity
o Can also be used for lower electrical or mechanical requirements
7 Overvoltage protection in AC rail networks

7.1 Overvoltage protection in railway power supply

The 50 Hz transmission networks of railway services do not differ significantly from those of the public energy supply. Therefore the same rules apply for the use of surge arresters, see application guideline [1].

However, the 16.7 Hz networks used for European railways are structured differently. Figure 10 shows a schematic example of the railway power supply with the locations of surge arresters used by Schweizerische Bundesbahnen (SBB) in Switzerland. The two current conductors in the 132kV network each have a voltage of 66 kV (180° out of phase) to earth. The center of some transformers is effectively earthed. In Germany and Austria, the transmission networks are earthed via coils. If a single-phase earth fault occurs in such a transmission network, the other, non-faulty phase can reach an increased voltage to earth.

MO arresters can withstand an increased 16.7 Hz voltage for the duration of an earth fault, depending on their time overload capacity. The arrester continuous operating voltage $U_c$ is chosen according to the duration of the fault and the voltage in the fault. In the present case, a POLIM-H 84 N with $U_c = 84$ kV is used, which has a residual voltage of $U_{res} = 268$ kV with a rated discharge current of $I_n = 20$ kA. Correspondingly, the arresters for the transformer neutral are designed for transformers that are not effectively earthed, for example with $U_c = 44$ kV.

7.2 Surge protection of rail systems and locomotives

It is recommended to provide surge arresters in the rail systems at the following locations between high voltage and earth:

- At all feed-in points where the cables are connected to the overhead line.
- At joints where reflections from transient surges can lead to flashovers, e.g. at distributing points, end of sections.
- At power take-off points when e.g. a cable is connected to the overhead line to take energy for a point heater.
- At the entrance to tunnels, to protect the installation in the tunnel against flashovers as a result of transient surges.

Normally, when designing the arresters in an AC system, three important characteristics, among others, must be considered: the highest continuous and TOV voltage that arises in the network, the protection level of the arresters and the energy absorption capacity of the arresters.

In AC railway systems the situation is different. According to Table 1 and Figure 3, we have definitions of the highest permanent voltage $U_{max1}$ and of the highest non-permanent voltage $U_{max2}$, which can appear for maximum 5 min. as defined in the specification, but it is not known how often and at which time intervals. Voltage fluctuations above these defined values have been observed in real railway systems, too.

It is very important that the arresters in the system shall be stable from the thermal point of view, no matter which stresses appear.
As the modern ABB MO surge arresters have a very favorable protection level and high energy absorption capability, it is recommended to lay the continuous voltage \( U_c \) of the MO arrester similar or, ideally, significantly higher than \( U_{\text{max}2} \). The surge protection of the devices is still guaranteed.

The following minimum value applies to the selection of the MO arrester:

\[
U_c \geq U_{\text{max}2}
\]

Since, in unfavorable cases, harmonic waves or energy recovery can lead to considerable voltage fluctuations in these railway networks, an additional margin of approx. 10% is recommended when selecting the \( U_c \). The following recommendation applies to these networks when selecting these arresters:

\[
U_c \geq 1.1 \times U_{\text{max}2}
\]

The rated voltage \( U_r \) is irrelevant for the selection of the MO arrester in this application.

### 7.2.1 Arrester selection in the 25kV/50Hz AC network

With \( U_{\text{max}2} \) from Table 1 the minimum continuous voltage for the MO arrester is:

\[
U_c \geq 29 \text{ kV}
\]

The following recommendation applies to higher operational safety in unfavorable cases:

\[
U_c \geq 32 \text{ kV}
\]

The arrester type POLIM-H 32N is recommended as an arrester for fixed installations along the overhead contact lines and in the stations. The co-ordination concept of the arresters for a good overvoltage protection has proven useful for traction vehicles, see Figure 11. The main arresters are on the roof close to the pantograph. The very high quality POLIM-H 32N is recommended for this application. Cables lead from the pantograph to the inside of the transformer, which is protected against overvoltages by a slightly weaker surge arrester, type POLIM-S 34N or POLIM-I 34N. Choosing a slightly higher continuous voltage for the arrester on the transformer ensures that the energies of the overvoltages occurring in the network are mainly absorbed by the main arresters on the roof. As far as is technically possible, there is also a version with a reduced overall height for use on rail vehicles.

### 7.2.2 Arrester selection in the 15kV/16.7Hz AC network

With \( U_{\text{max}2} \) from Table 1 the minimum continuous voltage for the MO arrester is:

\[
U_c \geq 18 \text{ kV}
\]

The following recommendation applies to higher operational safety in unfavorable cases:

\[
U_c \geq 20 \text{ kV}
\]

The arrester type POLIM-H 20N is recommended as an arrester for fixed installations along the overhead contact lines and in the stations. The co-ordination concept of the arresters for a good overvoltage protection has also proven itself at this voltage level - with the very high-quality POLIM-H 20N on the roof and a POLIM-I 22N inside to protect the transformer.
8 Arresters for DC rail networks

8.1 Applicable standards
The standards EN 50123-5 [18] and IEC 61992-5 [19] have been applied to the dimensioning and type testing of surge arresters in DC rail networks. In 2012, the new standard EN 50526-1 appeared, which replaces EN 50123-5. IEC 61992-5 was also revised and replaced by IEC 62848-1, which largely corresponds to EN 50526-1. EN 50123-5 and IEC 61992-5 are no longer valid.

While EN 50123-5 or IEC 61992-5 was largely a copy of IEC/EN 60099-4 for AC voltage applications with only minor adjustments to the changed requirements of a DC network, EN 50526-1 and IEC 62848-1 take into account the special requirements of the DC rail network much better.

8.2 Definitions of important arrester parameters

Continuous operating voltage of an arrester $U_c$
Maximum permissible DC voltage value that may be continuously applied to the arrester terminals.

Rated voltage of an arrester $U_r$
Voltage by which the arrester is designated. Due to the special properties of DC rail systems, the rated voltage of a DC arrester corresponds to the continuous operating voltage of the arrester.

Nominal discharge current of an arrester $I_n$
The peak value of the lightning current impulse, according to which an arrester is classified as per EN 50526-1.

Residual voltage of an arrester $U_{res}$
Peak value of the voltage across the arrester terminals when a discharge current flows.

Lightning impulse protection level $U_{pl}$
Maximum residual voltage at nominal discharge current $I_n$.
The ratio $U_{pl}/U_c$ indicates the protection level of a surge arrester. The smaller the ratio, the lower the arrester limits the overvoltage and the better it protects the device.

Charge transfer capability $Q_t$
Maximum charge per impulse that the surge arrester can absorb during the charge transfer test and during the operating duty test according to EN 50526-1/IEC 62848-1 without becoming thermally unstable.

Rated short-circuit current of an arrester $I_s$.
Maximum DC current that can flow for a specified time if the arrester fails or has been overloaded.
### 8.3 Technical data of ABB arresters

EN 50526-1/IEC 62484-1 identifies the three arrester classes DC-A, DC-B and DC-C according to increasing charge and energy absorption capacity for use in DC rail networks.

ABB offers a wide range of arrester types for these classes that cover all possible requirements. All arresters focus on the reliability and durability of the products.

Important data regarding the arresters recommended for use in DC rail networks are summarized in Table 4.

Further information on the properties of these products can be found in the data sheets at www.abb.com/arrestersonline.

### 8.4 Type tests in accordance with EN 50526-1 and IEC 62848-1

Type tests are tests which are carried out once to demonstrate that a special arrester type operates properly under the loads defined in the standard. The following type tests are to be carried out on the arresters:

- Insulation withstand test on the arrester housing, in other words the voltage withstand strength of the outer insulation with DC voltage, when wet and with lightning current impulse voltage.
- Testing the residual voltage of the MO resistors at various current pulses, i.e. the protection characteristics with steep current impulse, lighting current impulse and switching current impulse.
- Test of the charge transfer capacity of the MO resistors with rectangular surge currents.
- Operating duty testing on complete arresters, i.e. thermal energy absorption in the operating duty test.
- Mechanical tests and tightness testing.
- Evidence of pressure relief in the event of a short circuit with DC, in other words, the behavior when overloaded.
- Testing under artificial pollution over 1000 h in the salt spray chamber under DC voltage applied and UV testing of the insulating material.
- Test to prove long-term stability under normal conditions (aging test with DC).

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**Table 4: ABB surge arresters for DC rail systems**

<table>
<thead>
<tr>
<th>Types</th>
<th>POLIM-C..HD</th>
<th>POLIM-H..ND</th>
<th>POLIM-H..SD</th>
<th>POLIM-R..ND</th>
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<th>POLIM-4.5 ID</th>
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<td>Arrester class in accordance with EN 50526-1/IEC 62484-1</td>
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<td>DC-C</td>
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<tr>
<td>Continuous operating voltage $U_c$</td>
<td>1.0 ... 4.7 kV</td>
<td>1.0 ... 4.7 kV</td>
<td>0.14 ... 4.2 kV</td>
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<td>1.0 ... 4.7 kV</td>
<td>4.5 kV</td>
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<td>Nominal discharge current $I_n$</td>
<td>10 kA</td>
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<td>10 kA</td>
<td>10 kA</td>
<td>20 kA</td>
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<td>Charge transfer capability $Q_t$</td>
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</tbody>
</table>

*Main types, recommended according to required charge transfer capability*

*O Can also be used for lower electrical or mechanical requirements*
8.5 Railway-specific special tests

8.5.1 Vibration and shock tests
If MO arresters are used on locomotives or other rolling stock, they are exposed to constant vibrations and occasionally shock loads. The ABB MO arresters recommended for this application have been successfully tested for shock and vibration in accordance with IEC 61373. These arresters are supplied with reinforced base plates.

8.5.2 Wind tunnel tests for high-speed trains
When installing the MO arrester on high-speed trains, they are exposed to high wind speeds, which can cause the sheds of the silicone insulation to resonate. There is also a risk that the high wind pressures will push the sheds down and thus reduce the flashover and creepage distances. The ABB MO arresters recommended for this application have been successfully tested in the wind tunnel of the German Aerospace Center (DLR) up to a speed of 360 km/h [18] and are suitable for this use.

8.5.3 Fire behavior test
Extensive evidence of fire behavior is required for use in railways. The silicone elastomers used to isolate ABB MO arresters have been tested in accordance with various test standards, including for flue gas development, optical density of the flue gases, composition of the flue gases and oxygen content, and comply with EN 45545-2 among other standards. The silicones used meet hazard class HL2 and partly HL3 for the requirements R22 (indoor use) and R23 (outdoor use).

8.6 Final and acceptance tests
All arresters are individually tested in accordance with EN 50526-1 and IEC 62848-1. As part of the final test, the reference voltage and the leakage current at the continuous voltage \( U_c \) are determined as well as the freedom from partial discharge. Acceptance tests must always be agreed between the manufacturer and the purchaser.
9 Overvoltage protection in DC rail networks

9.1 Overvoltage protection in railway power supply
DC rail networks differ fundamentally from AC rail networks in that the rails and thus the return conductor are laid insulated against ground. This is necessary to avoid stray current corrosion in ground installations. Due to the insulated laying of rails, potential differences occur between grounded system parts and the trains on rail potential. In addition to the usual overvoltage protection of systems and devices, measures for personal protection against impermissible touch voltages must also be taken with DC rail systems. See Chapter 10.

The protection of electronic control and information systems against overvoltages in rail systems is becoming increasingly important for economic reasons. A publication by Hamburger Hochbahn AG [20] shows that damage caused by overvoltages during thunderstorms or power switching operations has an increasingly significant economic impact due to failure of the electronics and data transmission technology.

9.2 Overvoltage protection of DC rail networks
As with AC rail networks, it is recommended for DC rail networks to provide surge arresters at the following locations in the rail systems:
• At all feed-in points where the cables are connected to the overhead line.
• At joints where reflections from transient surges can lead to flashovers, e.g. at distributing points, end of feed sections or routes
• At power take-off points when e.g. a cable is connected to the overhead line to take energy for a point heater.
• At the entrance to tunnels, to protect the installation in the tunnel against flashovers as a result of transient surges
• Additional arresters are recommended for route sections that are subject to frequent lightning strikes, for example on bridges or on exposed overland routes.
• On feed lines in the substations
• Between return conductor and earth, if this arrester is not already integrated in the voltage limiting device. This is necessary because the return conductors in DC traction systems are insulated from earth.

Figure 12 shows the protection concept in DC rail networks.
Differentiation between functions A1 and A2
The A1 arresters in the overhead line and the A1 arresters in the substations limit the overvoltage that occurs when lightning strikes to a harmless value. The A2 arrester between the return line (rail) and the earth of the building should limit the potential increase of the rails and conduct the lightning discharge to earth.

In light of their high energy absorption capacity, their low residual voltage (good protection level $U_{pl}/U_{c}$) and their secure construction, the ABB arresters are ideal for these applications.

9.3 Surge protection of DC traction vehicles
In the beginning, surge protection for DC traction vehicles was designed in the form of horn arresters. Around the 1930s, spark gap arresters with non-linear SiC resistors were introduced. Today, MO surge arresters with no spark gaps are state of the art in the DC rail networks and on traction vehicles. The arresters are not only installed on the roof, but also in the immediate vicinity of the converter. This requires a co-ordination concept of the arresters for a good over-voltage protection, see Figure 13.

A surge arrester type POLIM-H .. ND is recommended to be installed on the roof and a small surge arrester type POLIM-C ..HD for protection of the converter inside. The $U_c$ of both arresters shall be equal.

Two-system traction vehicles also have a surge arrester for the AC high voltage (e.g. a POLIM-H 32N for the 25kV/50Hz network) between pantograph and main switch, another arrester with lower energy absorption capacity and higher residual voltage to protect the AC transformer (e.g. a POLIM-I 33N) and a surge arrester to protect DC installations (e.g. a POLIM-H 2.5ND for a 1.5 kV DC rail network), see Figure 14.
Figure 13: Arrangement of the arresters in a traction vehicle in the DC rail network.

Figure 14: Arrangement of the arresters in a 2-system traction vehicle (25kV/50Hz AC and 1.5kV DC)
9.4 Selection of arresters in urban traffic

As with MO arresters for AC rail networks, it is important to select the continuous voltage $U_c$ higher than the maximum non-permanent voltage $U_{\text{max}2}$, so that the following applies:

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

According to Table 1 $U_{\text{max}2} = 1000 \, \text{V}$ for a network with a nominal voltage of up to $U_n = 750 \, \text{V}$. From this follows the requirement for the surge arrester:

$$U_c \geq 1000 \, \text{V}$$

For traction vehicles and overhead lines (arrester A1), POLIM-H 1.0 ND is recommended with $U_c = 1 \, \text{kV}$. In the stations, type POLIM-H 1.0 ND or POLIM-H 1.0 SD can be used as A1 arresters. POLIM-H 1.0 SD has the same electrical properties as POLIM-H 1.0 ND, but is mechanically weaker and has a significantly smaller housing. It is therefore suitable for fixed installations in systems with limited space. Since, in unfavorable cases, the voltage fluctuations in the railway system can be significant, even higher than expected. In these cases, for higher operational safety the same surge arrester types but with $U_c = 1.5 \, \text{kV}$ are recommended.

These arresters meet and exceed the requirements and thus offer the best protection and optimal safety for the traction current systems for DC trains. The type POLIM-R..ND or POLIM-H..SD is recommended for use as an A2 arrester.

The arresters POLIM-H..ND, POLIM-H..SD and POLIM-R..1ND contain active parts with MO resistors with the same diameter, so they are matched to each other both in terms of current/voltage characteristics and energy absorption.

The arrester POLIM-R..2ND contains two MO resistors connected in parallel with the same diameter as its active part and thus offers almost double the charge absorption capacity at an even lower, i.e. better, level of protection.

9.5 Selection of arresters in long-distance traffic

Since the switching overvoltages of mechanical DC switches and the voltage fluctuation with the nominal voltages of 1.5 kV and 3.0 kV can reach very high values, an additional margin is recommended for the selection of the $U_c$ for the A1 arrester in order to ensure more operational safety in unfavorable cases.

For a network with $U_n = 1500 \, \text{V}$ $U_{\text{max}2}$ from Table 1 results in a minimum continuous voltage for the MO arrester (A1) of: $U_c \geq 1950 \, \text{V}$. For this network, an arrester with $U_c = 2.0 \, \text{kV}$ is recommended, or $U_c = 2.5 \, \text{kV}$ for higher operational safety.

For a network with $U_n = 3000 \, \text{V}$ $U_{\text{max}2}$ from Table 1 results in a minimum continuous voltage for the MO arrester (A1) of: $U_c \geq 3900 \, \text{V}$. For this network, an arrester with $U_c = 4.2 \, \text{kV}$ is recommended, or $U_c = 4.7 \, \text{kV}$ for higher operational safety.

In networks with $U_n = 3000 \, \text{V}$ the arrester POLIM-H 4,2 ND with $U_c = 4,2 \, \text{kV}$ or arrester POLIM-H 4,7 ND with $U_c = 4,7 \, \text{kV}$ is generally used. In regions that have strong thunder storms and networks which have to absorb 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 can absorb more than twice as much energy. For special requirements, we would be happy to advise you on the development of specific solutions.

The $U_c$ of an A2 arrester that is mounted on the connections of a voltage limiting device must be coordinated with its insulation capacity and trigger properties.

If an A2 arrester is used without a voltage limiting device, minimum $U_c$ according to EN 50526-3 [21] as per Table 5 are recommended:

<table>
<thead>
<tr>
<th>$U_n$</th>
<th>$U_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>750 V</td>
<td>300 V</td>
</tr>
<tr>
<td>1500 V</td>
<td>400 V</td>
</tr>
<tr>
<td>3000 V</td>
<td>500 V</td>
</tr>
</tbody>
</table>

---

Table 5: Minimum $U_c$ of A2 arresters
10 Voltage limiting devices

10.1 Introduction
The track systems of DC railway systems (return conductors) are laid insulated to prevent stray current in the ground. Voltage limiting devices are used with DC trains to ensure personal protection. In the event of a broken overhead line (fallen cable), an impermissibly high touch voltage between the tracks and the neighboring metallic structures (masts, railings, etc.) can occur. Voltage limiting devices are connected between earthed system parts (e.g. at train stops) and tracks which have been laid insulated. Voltage limiting devices monitor the potential difference at their terminals. If limit values specified in standards (EN 50122-1) are exceeded, they should cause temporary equipotential bonding, thus preventing the tapping of impermissible touch voltages by people in case a fault occurs (VLD-F) or during operation (VLD-O).

10.2 Definitions according to EN 50122-1
A voltage limiting device (VLD) has a high resistance when the applied voltage is low and becomes conductive when the specified value is exceeded. If the voltage drops, it can become high ohmic again or remain permanently conductive.
EN 50122-1 differentiates between two types of voltage limiting devices.

VLD-F: In the event of a fault with a connection from a live part of the traction power supply system to a conductive part that is not connected to the return circuit, the VLD-F protects against impermissible touch voltage by making it conductive and causing the power supply to trip. The VLD-F is connected between the touchable conductive part and the return circuit.

VLD-O: The VLD-O protects against an impermissible voltage caused by the rail potential in the event of operation and short circuit. The VLD-O acts as an equipotential bonding device and thereby limits the touch voltage. It connects earthed structures to the return line. De-energizing the line through a response by the VLD-O is not intended.

10.3 Classification according to IEC 50526-2
The standard EN 50526 [22], which was published in 2014, describes the requirements and tests for voltage limiting devices used in stationary DC rail applications. This standard differentiates between four classes of voltage limiting device:
• Class 1: Welding-shut spark gap
• Class 2: Voltage limiting device based on electronic switching elements (e.g. thyristors). Class 2.1 is uni-polar, class 2.2 is bi-polar.
• Class 3: Voltage limiting device based on a mechanical breaker
• Class 4: Voltage limiting device based on a mechanical breaker and additional electronic switching elements (e.g. thyristors)

Devices of classes 1 and 2 are passive, i.e. they do not require a power supply and can be used along the railway line.

Devices of class 1 are generally non recoverable, as the electrodes weld together due to the current flow and create a short circuit.

Devices of class 2 are recoverable within the specific load range. These devices switch off in the zero-current transition. In case of loads above and beyond this, the electronic switching elements alloy and create a short circuit.

Devices of classes 3 and 4 are recoverable within a specified load range and can break the specified load currents. These devices require a power supply for operation, they are designed for indoor use in the stations.
10.4 Structure and function of HVL voltage limiters

ABB produces two different types of voltage limiting devices, the HVL 60-0.3 with the nominal triggering voltage $U_{Tn} = 60 \, \text{V}$ and the HVL 120-0.3 with the nominal triggering voltage $U_{Tn} = 120 \, \text{V}$, see Figure 15.

The HVL (hybrid voltage limiter) is a voltage limiting device (VLD) used primarily in DC traction systems to protect against electric shocks. Impermissible touch voltages can occur in DC traction systems between track systems (return conductors) and earthed metal structures, as the track systems are laid insulated to limit stray currents. The HVL limits touch voltages regardless of whether they are purely DC or mixed voltages of both DC and AC voltages to the permissible limit values defined in EN 50122-1 and EN 50122-3 [23].

The HVL consists of the parallel connection of an MO resistor, two anti-parallel connected thyristors and an electronic control unit, see Figure 16. Transient surges caused by lightning and switching operations in the network are limited by the MO resistor. If surges occur for a longer period of time (milliseconds to hours) due to faults in the network or for operational reasons, the thyristors ignite to limit touch voltages. As soon as a zero-current transition occurs, the thyristors cut off the current flow and the original condition is restored.

Within the defined current range, the HVL is recoverable, i.e. it returns back to the insulating condition after the current flow. If, however, the short-circuit current is too high or active for too long in case a fault occurs, the thyristors could be overloaded, alloy and become very low resistance. In this case, both surge and personal protection are still guaranteed, but the measure for limiting stray currents is no longer in effect and the HVL must be replaced.

The HVL is a class 2.2 (bi-directional) voltage limiting device and is type-tested as per EN 50526-2. Mechanically, the HVL features a very rugged design. As with all high-voltage arresters from ABB, the active component is directly molded in using gray silicone. This well-proven design protects the device from any possible environmental stresses, such as UV radiation, vibrations and pollution. The HVL is corrosion resistant and can be used either outdoors or indoors. The HVL does not require a power supply from the mains grid. The HVL complies with both VLD-O and VLD-F functionality in the specified current range.
10.5 Definitions of important parameters

**Voltage limiting device VLD**
Protection device whose function is to prevent existence of an impermissible high touch voltage (VLD = Voltage Limiting Device)

**Triggering voltage** $U_T$
Voltage at which a VLD becomes conductive

**Nominal triggering voltage** $U_{Tn}$
Voltage at which a VLD becomes conductive when a DC voltage is present for a long period. This voltage is used to identify the VLD.

**Non-triggering voltage** $U_w$
Highest voltage below which a VLD does not trigger for any duration of the applied voltage

**Instantaneous trigger voltage** $U_{ti}$
Lowest voltage at which the VLD becomes conductive with a delay of 5 ms after it is applied

**Recoverable VLD**
VLD that recovers after triggering

**Non-recoverable VLD**
VLDs that remain permanently in their low-resistance status after triggering

**Rated current** $I_r$
Maximum value of the current that can be held by the VLD for one hour under specified ambient conditions without exceeding the heating limit values

**Short-time withstand current** $I_w$
Current that a VLD can carry in closed status, during a specified short time under prescribed conditions of use and behavior

**Leakage current** $I_L$
Current which flows through the terminals when the VLD is in open status

**Lighting current impulse** $I_{imp-n}$
Current pulse of the waveform 8/20 μs with the limit values 7 μs to 9 μs for the front time and 18 μs to 22 μs for the time to half value on the tail

**High current impulse** $I_{imp-high}$
Current pulse with a pulse shape of 4/10 μs or 8/20 μs, which is used as proof of the dielectric strength in the event of a direct lightning strike

**High-charge impulse** $I_{imp-hc}$
High-charge surge current of waveform 10/350 μs or a waveform with the same charge and similar duration, which is used as proof of the discharge capacity in direct lightning strikes

**Residual voltage** $U_{res}$
Value of voltage that appears between the terminals of the VLD during the passage of a specified current

**Response time** $T_R$
Time between the application of a voltage until the VLD becomes conductive

**Mixed voltage**
Voltage with significant alternating and constant components

10.6 Voltage limiting device technical data

Important data of the voltage limiting devices are summarized in Table 6. Further information on the properties of these products can be found in the data sheets at www.abb.com/arrestersonline.

### Table 6: Voltage limiting device technical data

<table>
<thead>
<tr>
<th>Type</th>
<th>HVL 120-0.3</th>
<th>HVL 100-0.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class (EN 50526-2)</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Nominal triggering voltage $U_{Tn}$</td>
<td>120 V</td>
<td>60 V</td>
</tr>
<tr>
<td>Non-triggering voltage $U_w$</td>
<td>96 V</td>
<td>48 V</td>
</tr>
<tr>
<td>Rated current $I_r$ (AC and DC)</td>
<td>95 A</td>
<td>95 A</td>
</tr>
<tr>
<td>Lighting current impulse $I_{imp-n}$</td>
<td>25 kA – wave 8/20 μs</td>
<td>25 kA – wave 8/20 μs</td>
</tr>
</tbody>
</table>
10.7 Type tests in accordance with EN 50526-2
Type tests are tests which are carried out on voltage limiting devices once to demonstrate that the device operates properly under the loads defined in the standard.

The following type tests are to be carried out:
• Checking the nominal triggering voltage and the non-triggering voltage
• Leakage current measurement
• Determination of the maximum load for DC short-time withstand currents and long-time withstand currents
• Determination of the maximum load for AC short-time withstand currents and long-time withstand currents
• Testing the response time as a function of the DC voltage and the mixed voltage (DC voltage with superimposed AC voltage)
• Testing the lightning impulse withstand capacity and charge dissipation with lightning impulse currents of different amplitudes and waveforms
• Degree of protection in accordance with IEC 60529 [24]
• Environmental testing of the materials used.

10.8 Final and acceptance tests
All voltage limiting devices of type HVL 60-0.3 and HVL 120-0.3 are individually tested in accordance with EN 50526-2. As part of the final test, the triggering voltage and the leakage current at the non-triggering voltage are determined. Acceptance tests must always be agreed between the manufacturer and the purchaser.

10.9 Use of voltage limited devices
Voltage limiting devices are connected between earthed system parts (e.g. at train stops) and tracks which have been laid insulated, see Figure 17.

Knowledge of the expected loads is necessary to determine suitable installation locations. The extent and duration of the potential differences and leakage currents that actually occur depend on numerous parameters concerning track construction, railway current and vehicle technology, as well as railway operating and external boundary conditions.

Typical locations for HVL devices in urban transport are train stations, stops and on grounded metallic structures in the track area that are accessible to the public, see protection concept in Figure 12.
11 Installation directions

In order to achieve the expected protection through the arrester it must be taken into consideration that arresters have a limited local protection area. The voltages at the arrester terminals and those on electrical equipment are not equal because of the transient wave occurrences between the connection point of the arrester and the equipment to be protected. The extent of the voltage on electrical equipment depends on residual voltage of the arrester itself, the rate-of-rise of the overvoltage wave, its traveling speed along the line and also the distance between the arrester and the equipment.

Therefore, it is essential that the arrester is placed as close as possible to the equipment to be protected. The high-voltage and earth connections must be as short and straight as possible. The earthing resistance must be low. A lower earthing resistance than 10 Ω is desirable as a standard value.

Further information on assembly and installation, maintenance, transport, storage and disposal can be found in the respective operating instructions.
Lightning overvoltage and switching overvoltage are also a risk for installations and equipment in electrical railways. MO surge arresters with no spark gaps reliably limit these overvoltages. The ABB arresters with silicone direct-molding have proven to be extremely reliable products in rail systems and especially on traction vehicles for many years.

The HVL type voltage limiting devices, which have been further developed in accordance with the EN 50526-2 standard, offer reliable protection against impermissible touch voltages.

We would be happy to advise you on any questions you may have regarding the use of surge arresters and voltage limiting devices in rail systems. ABB has a very broad product portfolio for the special operating conditions in DC and AC rail systems.
13 Bibliography

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Application Guidelines, Overvoltage protection, Metal-oxide surge arresters in medium-voltage systems


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Part 1: Common Topics

Teil 1: Grundlegende Anforderungen – Luft- und Kriechstrecken für alle elektrischen und elektronischen Betriebsmittel


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[24] IEC 60529: Degrees of protection provided by enclosures (IP Code)
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