Surge arresters for protection of traction systems and rolling stock

1. General items

Electrical power for traction systems generally is transmitted to traction substations by high voltage overhead lines of 110 kV or 132 kV rated voltage and frequencies of 50 Hz, 60 Hz or 16.7 Hz. The voltage then is stepped down to the supply voltage of the traction system and converted into DC voltage if necessary. The high voltage overhead lines and the substations as well as the overhead contact system and the rolling stock are exposed to lightning overvoltages, which may result in big damages on the insulation of the electrical equipment. Therefore an overvoltage protection of the transformers within the substations, the supply points into the overhead contact system and the rolling stock always was necessary. Apart from the insulation, electronic devices increasingly used beside or within the rails must be protected against overvoltages, likewise a task which can be solved by modern surge arresters supplementary. The reason that surge arrester still had not been used every time was depended on mental reservations customers often had concerning their reliability. The introduction of gapless metal-oxide surge arresters where an extremly positive service experience over more than twenty years is given in the meanwhile, the permanent improvement of the sealing system as well as the increasingly used polymeric housings offer extrem reliability still in case of short circuit behaviour as a result of overload, so that there is still no reason to do without overvoltage protection of all equipment concerning rail applications.

2. Electrical properties of surge arresters

The active part of modern surge arresters consist of nonlinear metal-oxide (MO) resistors. The voltage dependence of these MO-resistors is sufficient, so there is no need for series spark gaps. At applied system voltage there is only a leakage current flowing of less than 1 mA. Requirements for gapless MO surge arresters used in AC systems higher than 1 kV are given in the standard IEC 60099-4. The standard DIN EN 50123-5 mentions special requirements for surge arresters in DC rail applications. References for the use of surge arresters are given in the application guide IEC 60099-5 (insulation coordination for rail applications is given in the standard DIN EN 50124-2).

In the following text some of the important terms used in this standards are explained:

**Rated voltage \( U_r \):**
The rated voltage is the AC voltage (r.m.s.) resp. DC voltage which can be applied in minimum 10 s to a prestressed (preheated) surge arrester without becoming thermally instable.

**Continuous operating voltage \( U_c \):**
The continuous operating voltage is the maximum permissible r.m.s. value of the AC voltage of system frequency resp. the maximum permissible DC voltage which is allowed to be applied to the surge arrester continuously.

**Voltage-time- (V-t-) Characteristic:**
The voltage-time-characteristic gives the maximum permissible time duration for the application of a voltage, which exceeds the continuous operating voltage.
Nominal discharge current $I_n$
The nominal discharge current is the lightning impulse current the surge arrester is designed for. Due to safety aspect for rail applications $I_n$ is chosen to be higher than the highest lightning impulse current which can be expected at the location of surge arrester installation. All surge arresters presented in this brochure show a nominal discharge current of 10 kA, wave shape 8/20 µs due to enhanced safety margins of design. However lightning currents exceeding 5 kA are not expected within traction systems.

Lightning impulse protection level of a surge arrester
The lightning impulse protection level of a surge arrester is equivalent to its residual voltage at the nominal discharge current. The residual voltage of a surge arrester is the voltage drop across the terminals of an arrester when the lightning impulse current is flowing through it. The amplitude of the residual voltage depends on the amplitude of the discharge current as well as on the steepness of its waveshape. The residual voltage at discharge currents of high front steepness is about 6 % higher than that at a comparable lightning impulse current with a wave shape 8/20 µs. Because amplitudes of discharge currents exceed a value of 3 kA very seldom, residual voltages above the lightning impulse protection level will not occur.

Protective zone of a surge arrester
It is important to note, that a surge arrester only has a limited spatial protective zone. The protective zone is dependent on the amplitude of the residual voltage, the steepness of the overvoltage and the withstand voltage of the insulation to be protected. The surge arrester has to be installed as close as possible to the device to be protected. The recommended line length between the location of surge arrester installation and the device to be protected is 10 to 15 m within a medium voltage substation.

Close-up strike
Considerations concerning capacity and protective ability of a surge arrester require in minimum one suspension or post insulator between the location where the lightning hit the line and where the surge arrester is installed which relieves the surge arrester due to its flashover. If this is not the case a so called close-up strike is given. This can not be handled by a surge arrester and always leads to its overload. While close-up strikes can be avoided within high voltage systems in most of the cases due to e.g. earth wires, they can not be suspended within medium voltage systems due to economical reasons. Nevertheless, an overload of a surge arrester still is a very rare event and effects far less than 1 % per year of all installed surge arresters.

Short circuit capability $I_s$ and overload behaviour
The short circuit capability means, that a surge arrester can lead a short circuit current after overload without violent shattering. Since surge arresters for rail applications are very often installed in areas with public access, the behaviour in case of overload is of high importance. The overload behaviour of Siemens surge arresters is controlled by using a pressure relief membrane. Compared to rigid overpressure protection this membrane opens extremely fast. The pressure relief membrane is used for surge arresters of all system voltages and has been proven to be reliable for 30 years. A further improvement of the short circuit behaviour is given by using polymeric housings instead of porcelain housings where thermal mechanical break can not be excluded completely. However, when using polymeric housings the short circuit behaviour is highly dependent on the design. Regarding DC traction surge arresters of type 3EB2, that are used in systems with no public access, the MO resistors are directly moulded with silicone rubber. In case of overload the arc burns through the housing very fast so that there will be no pressure built up. It can be guaranteed to a wide extent, that parts are not catapulted away from a failed surge arrester. For traction surge arresters of type 3EB1 that are used on the towers of overhead lines and on rolling stock, the same design is used than for Siemens high voltage surge arresters: onto a fiber reinforced plastic tube of high mechanical strength sheds made of high temperature vulcanized silicone rubber are moulded. The bottom flange is equipped with the short circuit and sealing system which is also proved thousandfold within high voltage surge arresters. In case of surge arrester overload this leads to a mechanically totally integer housing without breaking of the housing. The arc does not cut through the polymeric housing and the hot gases are lead to the outside through calculated gas diverter nozzles with the result, that
the arc commutates from the inside to the outside. No parts are ejected from the inside, the mechanical strength of the surge arrester is kept so that it can be used as a post insulator unscrupulous.

3. Supply voltages of traction systems

Supply voltages of traction systems are given in IEC 60850. The following terms and definitions are used there among other things:

- **Nominal voltage** $U_n$
  Designated value for a system

- **Highest permanent voltage** $U_{\text{max}1}$
  Maximum value of the voltage likely to be present indefinitely

- **Highest non-permanent voltage** $U_{\text{max}2}$
  Maximum value of the voltage likely to be present for a maximum of 5 min

The following voltages for traction systems are defined:

<table>
<thead>
<tr>
<th>$U_n$</th>
<th>$U_{\text{max}1}$ (V)</th>
<th>$U_{\text{max}2}$ (V)</th>
<th>$U_{\text{max}3}$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>750 V DC</td>
<td>900</td>
<td>1000</td>
<td>1270</td>
</tr>
<tr>
<td>1500 V DC</td>
<td>1800</td>
<td>1950</td>
<td>2540</td>
</tr>
<tr>
<td>3000 V DC</td>
<td>3600</td>
<td>3900</td>
<td>5075</td>
</tr>
<tr>
<td>15000 V 16,7 Hz</td>
<td>17250</td>
<td>18000</td>
<td>25300</td>
</tr>
<tr>
<td>25000 V 50 Hz</td>
<td>27500</td>
<td>29000</td>
<td>38750</td>
</tr>
</tbody>
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4. A1 - A2 surge arrester conception according to VDV-Schrift 525 for applications in DC systems

Recommendations are given for effective overvoltage protection in case of lightning strikes to owners of DC traction systems by the publication no. 525 of „Verband deutscher Verkehrsunternehmen“ (VDV).

The earthing of current systems is most important when conceptions for lightning protection are planned. If rails of DC traction systems are isolated from earth for reduction of stray current corrosion as it is required for new rails, they cannot be used as earth terminations. In this case low resistance tower footings, driven piles, reinforcements of steel concret location lines or separate earth rods must be used as earth terminations. However, rails laid without any measures for isolation generally show only a low leakage resistance and can be used as earth terminal. Though the current than will be discharged via the rails endangering electrical or electronic equipment located near or within the rails. Effective remedies against overvoltages caused by this process are additional surge arresters within this equipment.

To get a complete protection of overhead contact system outdoor surge arresters "A1" according to VDV 525 should be installed at each supply point, at the end of supply sections and dead-end feeders, at coupling points as well as at current taps. Additional A1 surge arresters are recommended if sections are hit by lightning strikes very often, e.g. on bridges or on long distances.

Connecting supply and return lines in substation with surge arresters is an essential element of a conception of overvoltage protection in traction systems. Surge arresters that are dimensioned in
two different ways are used for that purpose. Surge arresters of type A1 are mounted between section circuit breakers resp. cable terminals and return line. Unavoidable potential rise of a return line as a result of a lightning impulse current is limited by a surge arrester of type A2 mounted between return line and structure earth.

Although metal oxide surge arresters are devices of extremely high reliability with failure rates of less than 1 % per year, a failure may occur under unfavourable circumstances, which thereafter will lead to a permanent conductivity of the surge arrester of type A1. If the rails show a small leakage per unit length, the ground electrode in this case may take an inadmissible high fault voltage for a longer time. However, if an additional surge arrester of type A2 with a low continuous operating voltage (120 V ≤ Uc ≤ 300 V) is mounted between ground electrode and return line this surge arrester will fail intentional as well. In this way the fault voltage will be limited and the section circuit breaker will be released by feeding from the overhead traction system.

5. Selection of surge arresters

Selecting a surge arrester for a.m. system voltages it should be taken into account, that the continuous operating voltage of the surge arrester is equal to or higher than the highest nonpermanent voltage of the system, so

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

That surge arrester will be selected, where the \( U_c \) is either equal to \( U_{\text{max}2} \) or where the \( U_c \) follows \( U_{\text{max}2} \) within a type series. When this selection rule is used, all other operating conditions of the surge arrester are fulfilled automatically.

The type series of the Siemens surge arresters are designed in correspondence with the requirements of common traction systems. On demand special designs can be realised any time.

The following surge arrester types are available for different locations of traction systems:

- Protection of equipment in high voltage substations 110 kV to 380 kV:
  - Surge arrester type 3EP4, 3EP2 or 3EP3 with porcelain housing or surge arrester type 3EQ1, 3EQ4 or 3EL2 with polymeric housing

- Protection of overhead contact lines
  - in case of main line: surge arrester type 3EB1 with polymeric housing in case of mass transit:
  - also surge arrester type 3EC3 with porcelain housing (proved for decades)

- Protection of rolling stock
  - in case of main line: surge arrester type 3EB1 with polymeric housing in case of mass transit:
  - also surge arrester type 3EC3 with porcelain housing

- Protection of DC substations and limiting of potential raise of rails:
  - surge arrester type 3EB2 with polymeric housing (directly moulded)

More info?

If you would like to know more about our surge arresters please call us. It will be a pleasure to inform you in detail.

Tel. +49 (0)30 - 386 2 33 90
Fax +49 (0)30 - 386 2 67 21
E-Mail: arrester@siemens.de

Power Transmission and Distribution
High Voltage Division
Surge Arresters
Nonnen dammallee 104
D-13629 Berlin
http://www.siemens.com/ableiter

Siemens Aktiengesellschaft