High Voltage Surge Arresters for Protection of Series Compensation and HVDC Converter Stations
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Abstract
The efficiency of overhead power lines can be increased by series compensation or HVDC transmission. These complex systems can be protected from overvoltages by metal oxide surge arresters. Both porcelain and polymer tube design surge arresters are used for these applications, however, polymer tube design surge arresters offer various advantages over porcelain arresters such as light weight, extremely high mechanical resistance and safe short circuit behaviour. Type and routine tests of surge arresters for series compensation and HVDC stations ensure the general functionality and quality of these devices. The rating of surge arresters for series compensation and HVDC stations follows different consideration as the rating of standard high voltage surge arresters. While the latter ones are rated by mainly taking standard lightning, switching and temporary overvoltages into consideration, the rating of surge arresters for series compensation and HVDC converter stations is given by internal overvoltages due to operating and fault conditions.

1. Introduction
The transmission of electric energy over long distances by high voltage AC overhead transmission lines is limited by the inductance of the line. Above a certain length, the magnitude of which depends on the geometry of the system and its voltage, the voltage drop across the inductive impedance reaches a value which makes the system ineffective. There are two countermeasures to reduce or completely avoid the inductive current and thus to increase the efficiency of an overhead line: The installation of series compensation (SC) stations within the AC overhead line [1], or the transmission by high voltage direct current (HVDC).

The equipment used in SC or HVDC stations, e.g. capacitors, reactors, transformers, filters or valves, are exposed to overvoltages of different origin. Lightning strokes into the electric power system, the station itself or into its vicinity lead to lightning overvoltages. Switching action within the system including the periodic switching of the HVDC converter valves cause switching overvoltages. Certain operating conditions due to load flow control cause temporary overvoltages. Finally, overvoltages may be caused by internal or external faults and subsequent short circuit current. Without countermeasures, occurrence of these overvoltages in the system can lead to breakdown of the equipment insulation and its failure.

In order to protect the equipment from overvoltages, surge arresters are used within the system. The purpose is to always limit the voltage across the terminals of the equipment to be protected below its insulation withstand voltage. This is achieved by connecting elements with an extremely non linear voltage current characteristic in parallel to the terminals of the equipment. So called metal oxide (MO) surge arresters containing ceramic bodies mainly made from zinc oxide (ZnO) and bismuth oxide are used nowadays [2].

To some extend, there are differences in the design and testing, but particularly in the rating of surge arresters for protection of SC and HVDC stations as compared to arresters for standard AC high voltage applications. While the rating of standard surge arresters is mainly determined by standard lightning, switching and temporary overvoltages [3], the rating of SC and HVDC surge arresters is based on overvoltages by fault conditions or internal overvoltages. In this paper, the design, testing and application of surge arresters for protection of SC and HVDC converter stations will be explained.

2. Design, Rating and Testing of Surge Arresters
In this chapter, the design, electrical rating as well as type and routine testing of surge arresters in general will be introduced. Since arresters for SC and HVDC stations are somewhat different from each other and different from standard surge arresters, only very brief information about some basic considerations will be given. More details about the design, rating and testing of high voltage surge arresters can be found in [4].
2.1. Design of Surge Arresters

In the past twenty years there were two major changes in the technology of surge arresters. Firstly, the gapped silicon carbide (SiC) arrester technology was replaced by the gapless metal oxide (MO) arrester technology in the late seventies to early eighties of the last century. As a consequence, the protection characteristic was improved, the reliability was dramatically increased to failure rates close to zero and the design became much easier. In the late eighties to early nineties of the last century, polymeric housings were introduced. After porcelain housings are almost replaced by polymer housings in the medium voltage distribution systems nowadays, polymer technology is increasingly used in high voltage power systems even up to 800 kV. The success of polymer housings lies in the versatility of the possible designs which allow a wide range of arresters with respect to mechanical properties, short circuit behaviour and costs. Nowadays, basically four different designs can be distinguished, namely porcelain design, polymer tube design, polymer cage design and polymer wrapped design [5]. However, polymer cage and wrapped design do not play an important role for SC and HVCD surge arresters, but mainly porcelain and polymer tube design are used for this application.

As indicated in Figure 1, both porcelain and polymer tube design surge arresters consist of a hollow core housing, a stack of MO elements and a flange including the sealing and pressure relief system. The sealing and pressure relief system includes the pressure relief membrane, the sealing gasket and some adjacent metallic parts for fixture. Instead of a porcelain housing, a hollow core compound insulator which consists of a fibre reinforced plastic (FRP) tube with polymer sheds moulded onto forms the housing of the polymer tube design surge arrester. Usually, silicone rubber is used as shed material rather than EPDM due to its excellent chemical and physical properties.

![Diagram of porcelain and polymer tube design surge arresters](image)

The most important part of porcelain and polymer tube design surge arresters with respect to reliability and safety is the sealing and pressure relief system. The sealing system must be designed to prevent ingress of moisture for the whole lifetime. This can only be achieved by an appropriate but most easy construction and a very careful choice and combination of the materials. In case of an arrester failure and internal short circuit, the pressure relief system must release the pressure inside the housing which is caused by the arc heat before the housing is violently destroyed by the pressure shock wave. It must be pointed out that an arrester failure is a very rare event. While gapped SiC surge arresters failed quite frequently, the failure rates of modern MO surge arresters are comparable with other equipment such as transformers or instrument transformers. In most cases of MO arrester failures these were caused by deficiency of the sealing system due to transportation damage or stressing the arrester above its specification, e.g. by direct lightning strokes with extremely high currents or impermissible temporary overvoltages.

The porcelain housing is designed to withstand the internal pressure and arc heat and remain mechanically undamaged during internal flow of short circuit current and pressure relief. However, occasionally the arrester housing will collapse after the arc left the housing. This is caused by thermal mechanical stresses within the housing by the arc heat on the surface of the porcelain. As shown in Figure 2, the effect is that
the arrester falls into pieces in a non violent manner not endangering the surrounding substation equipment nor personnel in its vicinity. However, this behaviour implies that porcelain arresters must never be used as supporting insulator but a post insulator requiring additional space must always be installed.

Regarding the polymer tube design arresters, the mechanical properties of the FRP tube material are significantly better than of porcelain resulting in higher cantilever strength and headload. Furthermore, the mechanical properties may be adjusted according to the manufacturers or customers needs by varying the parameters of the FRP tube such as wall thickness or fibre angle. Thus, polymer tube design arresters are used where there are extremely mechanical requirements, in particular with respect to earthquakes. As opposed to porcelain, the FRP tube material does not show a secondary thermal break due to its ductile thermal mechanical properties. Even after short circuit and pressure relief the remaining mechanical strength of the FRP tube is at least 75% of the initial value. Thus, tube design polymer housing surge arresters may be used in a double function as arrester and post insulator saving space in the substation. Figure 2 shows a tube design polymer surge arrester after a short circuit test. Only traces of burning are left of the silicone rubber surface but the arrester housing has kept its full mechanical strength.

Figure 2: Short circuit behaviour of a porcelain design (left) and polymer tube design surge arrester (right)

A unique advantage of silicon rubber polymer tube design arresters over porcelain arresters is the hydrophobic effect of the material [6]. The self restoring hydrophobicity of the sheds dramatically reduces the risk of surface flashover or thermal instability due to field distortion. Furthermore, if the layer thickness does not become too thick, the hydrophobicity is transferred to pollution layers on the surface of the housing. Currently, tube design polymer arresters are more expensive than porcelain arresters. However, with increasing production of tube design polymer arresters further price reduction can be expected within the next years.

2.2. Rating of Surge Arresters

To effectively protect electric power systems and equipment, MO surge arresters do have to fulfil two basic requirements: The arrester must be rated to provide sufficient electric protection of the equipment installed in the system and it must remain thermally stable even under the most severe operating conditions.

To obtain sufficient electric protection the arrester must limit the voltage across the equipment below its withstand voltage including an appropriate safety margin. A typical rating for a standard outdoor surge arrester for the chinese 550 kV AC power system is indicated in Figure 3. As it can be seen, the protection level, i.e. the voltage at a lightning current impulse 20 kA 8/20 µs across the arrester terminals, amounts to 1010 kV. More details about the electrical rating of this particular arrester are given elsewhere [3]. With respect to thermal stability, the arrester must be rated not to exceed a specific internal temperature after absorption of energy and loading with voltage under normal and fault conditions. As shown in Figure 3, the limits are given by an unstable equilibrium between heat generation by the MO elements and heat dissipation by the arrester housing.
Due to the negative thermal characteristic of the ZnO material, the heat generation by the MO elements at a constant voltage will increase to a higher degree as the dissipation of this heat through the housing. As a consequence, there are two intersection between heat generation and heat dissipation characteristic. After heating the MO elements of the arrester, e.g. by single or multiple current impulses, below the limit of thermal stability the arrester will always return to the stable operating point. However, after heating above the limit of thermal stability the arrester will become thermally unstable and be destroyed. The effect of thermal stability is strongly dependant on the thermal properties of the arrester. Thus, the correct rating of a surge arrester in terms of thermal stability must be tested by a so called operating duty test on a prorated section of the arrester [7] [9].

The energy absorption capability of a surge arrester is not only limited by its thermal stability but by its impulse energy absorption capability as well. This effect refers to the limits of the individual MO element itself to handle current impulses. Depending on the particular current impulse, the MO element can be subject to puncture, flashover or break if its impulse energy absorption capability is exceeded. The influencing parameters are mainly current peak value, time duration and waveshape. Depending on the current peak value and time duration different failure modes, which limit the impulse energy absorption capability, are possible [13].

2.3. Testing of Surge Arresters

To ensure safe operation and an appropriate lifetime of surge arresters, type and routine tests are to be performed. The most important standards covering type and routine testing of surge arresters are IEC 60099-4 [7] and IEEE C62.11 [9]. While the type tests proof the general functionality of a surge arrester design, the purpose of the routine tests is to ensure the quality of each individual arrester unit. In the following the type and routine test as required by IEC 6099-4 are explained briefly and examples for routine test procedures and equipment are shown.

Type tests

Surge arrester type tests demonstrate the general ability of an arrester design to withstand the electrical, mechanical, thermal and environmental stresses which might occur within the lifetime of a surge arrester. These test are performed once on a certain number of samples and are to be repeated when significant changes of the arrester design are introduced. Apart from test on arrester units (e.g. short circuit test), certain tests on complete arresters (e.g. artificial pollution test) have to be performed. Type tests for Series Capacitor Banks and HVDC Converter Stations include the tests summarised in Table 1.

Routine tests

Surge arrester routine tests are performed on every single arrester unit in order to ensure the correct manufacturing and assembly of the arrester. Thus, routine testing is an important part of the quality assurance system of every manufacturer of surge arresters. As per IEC 60099-4, the routine tests as explained in Table 2 are required.
<table>
<thead>
<tr>
<th>Nr.</th>
<th>Test</th>
<th>Purpose</th>
<th>IEC 60099-4 Chapter(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Insulation withstand test</td>
<td>Demonstrates the ability of the arrester housing to withstand voltage stresses under dry and wet conditions</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7.2</td>
</tr>
<tr>
<td>2</td>
<td>Residual voltage test</td>
<td>Demonstrates the protective level of the arrester</td>
<td>5.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7.3</td>
</tr>
<tr>
<td>3</td>
<td>Long duration current impulse withstand test</td>
<td>Demonstrates the ability of the resistor elements to withstand dielectric and energy stresses without puncture or flashover</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7.4</td>
</tr>
<tr>
<td>4</td>
<td>Operating duty test</td>
<td>Demonstrates the thermal stability of the arrester under defined conditions</td>
<td>5.9</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>7.5</td>
</tr>
<tr>
<td>5</td>
<td>Short circuit test</td>
<td>Demonstrates the ability of the arrester to withstand short circuit currents without violent shattering of the housing. For polymer housed arresters this test also demonstrates the ability self-extinguish any fire caused by the arc</td>
<td>5.11</td>
</tr>
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<td></td>
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<td></td>
<td>Annex O</td>
</tr>
<tr>
<td>6</td>
<td>Test of arrester disconnectors</td>
<td>Usually not applicable for surge arresters for SC banks and HVDC stations, since disconnectors are virtually not used</td>
<td>5.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7.6</td>
</tr>
<tr>
<td>7</td>
<td>Artificial pollution test for porcelain housed multi unit arresters</td>
<td>Evaluation of the temperature rise of the internal parts due to a non-linear and transient voltage grading caused by the pollution layer on the surface of the arrester housing. Usually only applicable for “A” and “D” arresters of HVDC stations, generally not for SC arresters</td>
<td>Annex F</td>
</tr>
<tr>
<td>8</td>
<td>Internal partial discharge test</td>
<td>Measures the internal partial discharge rate</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>7.8</td>
</tr>
<tr>
<td>9</td>
<td>Seal leak rate test</td>
<td>Demonstrates the gas and water tightness of the complete system</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>13.7.4</td>
</tr>
<tr>
<td>10</td>
<td>Current distribution test for multi column arrester</td>
<td>Determination of the current through each column of parallel resistors</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8.1e</td>
</tr>
<tr>
<td>11</td>
<td>Bending moment test</td>
<td>Demonstrates the ability of the arrester to withstand the values for bending loads claimed by the manufacturer</td>
<td>13.7.2</td>
</tr>
<tr>
<td>12</td>
<td>Environmental tests</td>
<td>Demonstrates that the sealing mechanism and the metal parts of the arrester are not impaired by environmental conditions</td>
<td>13.7.3</td>
</tr>
</tbody>
</table>

Table 1: Summary of type tests for surge arresters as required by IEC 60099-4 [7]
Table 2: Summary of routine tests for surge arresters as required by IEC 60099-4 [7]

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Test</th>
<th>Purpose</th>
<th>IEC 60099-4 Chapter(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td>Measurement of reference voltage</td>
<td>Demonstrates the correct rating of the arrester, i.e. the use of a correct number of MO elements during assembly</td>
<td>2.35 5.2</td>
</tr>
<tr>
<td>b)</td>
<td>Residual voltage test</td>
<td>Demonstrates the protective level of the arrester. Usually, the sum of the residual voltages of the MO elements is calculated rather than performing a residual voltage test on the arrester unit</td>
<td>5.3 7.3</td>
</tr>
<tr>
<td>c)</td>
<td>Internal partial discharge test</td>
<td>Demonstrates the absence of partial discharges which might be caused by internal voids in the materials used or by particles</td>
<td>5.4 7.8</td>
</tr>
<tr>
<td>d)</td>
<td>Leakage check</td>
<td>Demonstrates that the sealing system was correctly assembled and that the arrester is gas and watertight</td>
<td>5.5 13.7.4</td>
</tr>
<tr>
<td>e)</td>
<td>Current distribution test for multi column arrester</td>
<td>Demonstrates that the MO elements were chosen for a current distribution between the columns within a specified range</td>
<td>5.6 8.1e</td>
</tr>
</tbody>
</table>

Measurement of reference voltage and internal partial discharge test can be performed together with the same test equipment. Preferably, a shielded test chamber should be used to prevent from external electromagnetic interference which might disturb the measurement. A test chamber including the control panel for both the reference voltage and partial discharge measurement is shown in Figure 4 (left). Figure 4 (right) also gives an example for voltage and current during measurement of the reference voltage. As can be seen, the reference current is already mainly resistive in order to avoid an influence of the measurement by stray capacitances.

Figure 4: Test chamber for measurement of reference voltage and partial discharge (left), oscillogram of reference voltage and current (right)

The residual voltage test is performed by applying standard lightning current impulses 8/20 µs, 10 kA to either the arrester units or the MO elements. Since measuring the residual voltage at complete arrester units needs large and expensive test equipment and is time consuming as well, IEC 60099-4 allows to calculate the sum of the residual voltages of the MO elements used to calculate the residual voltage of the arrester units and the complete arrester.

As explained in chapter 2.1, gas and water tightness of the arrester units is essential for the reliability of an arrester. Thus, the leakage test is a very important step of the arrester manufacturing process. IEC 60099-4 does not specify a particular method, but leaves it to the manufacturer to apply "...any sensitive method...". A possible method adopted here is to use the elasticity of the pressure relief membrane. As shown in Figure 5 (left), the pressure relief membrane lies flat in position 1 after assembly. However, if the pressure around the arrester is decreased and kept constant, the pressure relief membrane will bend upwards into
position 2 forced by the constant internal pressure inside the arrester. If the arrester unit is gas tight, the membrane will remain in position 2, if not, there will be a loss of pressure inside the arrester and a relaxation of the membrane towards position 2 with time. In Figure 5 (right) the insertion of an arrester unit into the test vessel can be seen.

![Diagram of pressure relief diaphragm]

Figure 5: Principle of leakage check (left) and test equipment (right)

**Special tests for surge arresters for SC application**

In addition to the tests according to IEC 60099-4 as shown in Table 1 special test have to be carried out on surge arresters for capacitor banks according to IEC 60143-2.

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Test</th>
<th>Purpose</th>
<th>IEC 60143-2 Chapter(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Power-frequency residual voltage test</td>
<td>Demonstrates the protective level of the varistor (complete arrester bank) at power-frequency currents with amplitudes of 0.5, 1.0 and 1.5 times the maximum prospective current</td>
<td>2.1.2.3.1.2.1</td>
</tr>
<tr>
<td>2</td>
<td>Switching impulse residual voltage test</td>
<td>Demonstrates the protective level of the varistor (complete arrester bank) at switching impulse current with a front time of 1 ms and amplitudes of 0.5, 1.0 and 1.5 times the maximum prospective current</td>
<td>2.1.2.3.1.2.2</td>
</tr>
<tr>
<td>3</td>
<td>Repeated energy withstand test</td>
<td>Demonstrates the ability of the varistor to withstand the current and energy duties for which it is designed</td>
<td>2.1.2.3.1.4</td>
</tr>
<tr>
<td>4</td>
<td>Energy withstand and power-frequency voltage stability test</td>
<td>Demonstrates the ability of the varistor to withstand maximum specified energy, followed by a possible temporary overvoltage sequence and thereafter show thermal stability energized at COV</td>
<td>2.1.2.3.1.5</td>
</tr>
<tr>
<td>5</td>
<td>Pressure relief test</td>
<td>Demonstrates the ability of the arrester to withstand short circuit currents and in addition a discharge of the capacitor bank from the protective level without violent shattering of the housing.</td>
<td>2.1.2.3.1.7</td>
</tr>
</tbody>
</table>

Table 3: Summary of special type tests for surge arresters for SC application.

**Special tests for surge arresters for HVDC application**

According to the application guide for metal oxide arresters without gap for HVDC converter stations CIGRE 33/14-05 modified operating duty tests have to be performed additionally to IEC 60099-4 taking into consideration the different stresses for the different surge arrester types within a HVDC converter station.
HVDC Arresters | DC bus / DC line arresters
--- | ---
Energy withstand test | Energy withstand test
6 high energy discharges | 18 line discharges
2 high current impulses | 2 high current impulses
1 high energy discharge | 2 line discharges
Verification of thermal stability | Verification of thermal stability
CCOV (AC voltage) | CCOV (DC voltage)

Table 4: Summary of special type tests for surge arresters for HVDC application.

3. Surge Arresters for Protection of Series Compensation Stations

As other stations, SC stations are protected by standard surge arresters against lightning overvoltages, too. These surge arresters, however, will not be considered here, but the focus will be on the surge arresters and arrester banks (MOV) for protection of the series capacitors of an SC station. A circuit diagram of an SC station is shown in Figure 6.

![Figure 6: Principle circuit diagram of SC station with MOV](image)

The purpose of a series compensation is to reduce the line voltage drop, to limit the load dependent voltage drops, to reduce the transmission angle combined with an increase of system stability and increase the transmission capability.

To design surge arrester banks system data are needed as the rated voltage, the rated impedance, the rated current, the short circuit power, the overload current cycle and the protection strategy during external and internal fault. For specified fault clearing sequences the MOV has to withstand stresses from external faults. This includes generally two subsequent faults, as they occur for example at a non-successful auto-reclosure. At internal faults the bypass devices are allowed to operate. However the arrester must be designed to withstand stresses from two subsequent internal faults. Using all given data an appropriate control and protection strategy can be established and coordinated resulting finally in energy rating including redundancy and protective level of the surge arrester bank.

The arrangement of surge arresters in parallel within a bank leads to an uneven current distribution between them in case of an overvoltage. This effect is caused by the high degree of non-linearity of that part of the voltage-current characteristic where the surge arrester has to operate in case of a system fault. To keep this uneven current distribution within a certain limit, e.g. ±5%, all columns belonging to one surge arrester bank have to be measured in a current distribution test.

Another main aspect is the short circuit behaviour of a single surge arrester as a part of a complete surge arrester bank. To avoid damage of further units in case of an arrester failure only surge arresters with pressure relief device should be used. These surge arresters can be installed on the platform in that way that the diverter nozzles show in a direction where the released gases do not damage the surrounding units. Surge arresters with porcelain housing can be destroyed in a secondary break as a result of pressure relief. Therefore surge arresters with composite housing are more suitable as they keep all their mechanical properties after a pressure relief.
4. Surge Arresters for Protection of High Voltage Direct Current Stations

An HVDC station as a rather complex system includes a number of different surge arresters for protection of the different pieces of equipment. As indicated in [10] and Figure 8, there are basically six types of surge arresters, which are commonly denominated by the letters “A” through “F”.

Type A: AC bus arresters which are located close to termination of incoming AC lines and close to transformers to give protection against lightning surges.

Type B: Valve arresters to protect the thyristor valves from excessive overvoltages. The protective level shall be as low as possible since the costs of the valves are roughly direct proportional to the insulation level across the valves.

Type C: Converter unit arrester for protection against overvoltages at the converter DC bus

Type D: DC bus or DC line arrester to protect the DC switchyard equipment connected to the DC pole.

Type E: Neutral bus arrester to protect the neutral bus and the equipment connected to it. Neutral bus arresters may be subjected to very large energy discharges in case of ground faults.

Type F: AC and DC filter arrester to protect the AC and DC filter reactors and capacitors

Figure 8: Principle circuit diagram of HVDC station with arresters
The dimensioning of the “B”- and “C”-arresters for protection of the semiconductors of the valve tower is particularly critical. On the one hand, the protection level must be maintained as low as possible in order to protect the very sensitive semiconductors and to minimise the number of these very costly components. On the other hand, the voltage and current wave shape across the arresters is extremely non sinusoidal and dependent on the load conditions and power flow of the HVDC station. As a consequence, the power dissipation of the arresters is variable with the load conditions and it is difficult to find the right compromise between protection of the valve tower and safe operation of the arrester. Simulation of the HVDC station including the various possible faults is an important tool for determination of the arrester voltage and current stress [10]. Tests on prorated sections of arresters for HVDC application have shown that the power dissipation under these loads is different as compared to pure sinusoidal waves shapes [12]. A typical example for voltage across and current through a “B”-arrester is shown in Figure 9.

![Figure 9: Voltage across and current through „B“-arrester of HVDC converter station](image)

The voltage consists of sections of sinusoidal waves and the current contains large peaks. The consequences of these current peak for the operating behaviour of surge arresters are not yet fully clarified. Negative effects have not been observed yet, measurements of the internal temperature of a “B”-arrester by surface acoustic wave temperature monitoring over a long period has never revealed any critical temperature [15]. However, a better understanding of the behaviour of MO arresters loaded with this kind of voltages and currents as opposed to purely sinusoidal waves can lead to a more efficient dimensioning of the arresters.

Regarding “B” and “C” arresters, polymer tube design surge arresters are clearly superior to porcelain arresters. Regarding the mechanical loading of the valve tower, which is usually hung from the ceiling of the valve building, polymer tube design surge arresters offer low weight which reduces the costs for the structure. In the very rare but theoretically possible case of a surge arrester short circuit, the failure mode of polymer tube design surge arresters as explained in chapter 2.1 prevents from collapse of the housing, the supporting structure and thus from damages of the surrounding equipment. These consideration apply to a certain degree to the “F” arresters for protection of the filter circuits. Since the filter capacitors and reactors are costly pieces of equipment, the arresters should be polymer type in order to avoid follow damages by collapse of the housing possibly following a short circuit. The “A”-, “D”- and “E”-arresters are uncritical in this respect and are porcelain types quite often. However, even here, polymer tube design surge arresters offer the advantage of leaving off post insulators in the station layout due to the outstanding mechanical strength even after short circuit.
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Biographies

Kai Steinfeld was born in Hilden, Germany on September 18, 1963. He studied Electric Power Engineering at the Berlin University of Technology, Germany and graduated at the Universities Institute of High Voltage Engineering with a work on the aging of polymer insulated medium voltage cables.

His employment experience includes Siemens Surge Arresters and Limiters, Berlin, where he began as test and development engineer in 2000. In 2001 he became director of the R&D department.

Reinhard Göhler was born in Reinsdorf near Hannover, Germany on January 20, 1955. He received the Dipl.-Ing. degree in 1980 in electrotechnical engineering from the Technical University of Braunschweig, Germany.

He joined Siemens AG, Switchgear Works, Berlin in the same year, where he began as a test and development engineer for surge arresters. In 1998 he became head of the surge arrester test field and in 2001 director of the sales department for special surge arresters.

Daniel Pepper was born in Hamburg, Germany on February 7, 1965. He studied electrical engineering at the Berlin University of Technology, Germany and graduated at the Universities Institute of High Voltage Engineering with a work on the PD behaviour of PE/XLPE-insulated MV cables at test voltages with variable shapes and frequencies.

He joined the HAEFELY Test AG, Switzerland in 2000 as a development and sales engineer for diagnosis and test equipment suitable for cable and transformer insulation systems. Since 2002 he is responsible for the development, design and sales of special surge arresters (HVDC and Series Compensation) at Siemens AG, Berlin.
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