New POLIM® medium-voltage surge arresters with silicone insulation

Surge arresters improve the reliability of power systems by reducing the interference caused by lightning overvoltages and switching transients. The past 25 years have seen ABB arrester technology go through three evolutionary stages. First, the arresters with plate-type spark gaps and SiC resistors were replaced by gapped arresters featuring magnetic blow-out for improved protection. This technology was eventually superseded at all the voltage levels by the far more efficient MO arresters with zinc-oxide resistors. The third major improvement came with the MVK, MWK and, more recently, POLIM® medium-voltage arresters, which have silicone-polymer insulation instead of ceramic insulators. POLIM surge arresters combine in an optimum way the outstanding protection properties of metal oxide, exceptional reliability in service and safety in the event of overloads.

A trend towards metal-oxide arresters with polymer insulation is especially evident today in the medium-voltage sector, where they are being used in systems rated to 52 kV and higher.

Gapless MO arresters with zinc-oxide resistors have several features that make them superior to gapped arresters [1]:

- Low protective level, assuring excellent protection, especially in the switching voltage range.
- Reduced protective level in cases of steep-fronted overvoltage waves in the switchgear environment [2].
- Higher energy absorption capacity, coupled with almost simultaneous action by parallel arresters in the same line branch [3].

Surge arresters with polymer insulation, especially those with silicone insulation, offer some important extra benefits:

- High immunity to every kind of pollution, since silicone is water-repellent.
- Well-suited for applications in salt-fog environments or where other forms of air pollution or contamination exist.
- No disintegration or explosion of the insulator as a result of electrical, and therefore thermal overloading.
- Practically no risk of damage during handling and transport.
- Approximately 50 percent reduction in weight and up to 25 percent reduction in length compared with ceramic housings.

Based on field results obtained over the last 10 years with the proven type MVK and MWK medium-voltage arresters, which also use silicone insulation, ABB has developed and introduced a new family of arresters that goes under the name of POLIM.

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Gapped and metal-oxide arresters

The MO arresters' advantages over the older gapped arresters have been described in detail elsewhere [3]. *Table 1* compares the relative merits of the two types of arrester.

The gapped arrester's unfavourable protective level is shown very clearly by **1**, which allows a comparison of the residual voltage curves of gapped arresters and MO arresters for specific, comparable current waves at a maximum power system voltage of 24 kV. The MO arresters offer better protection throughout the voltage-time range. At present, the ratio of the peak residual voltages at rated discharge current I_n (10 kA, 8/20 μs) to the continuous operating voltage lies in the region of 2.1:1; the protective level in the switching voltage range is even lower, being 1.9 or less. Another very important benefit is the better protection from the effects of waves with very steep fronts and direct lightning strikes. Here, MO arresters offer optimum protection, for example, for dry-type distribution transformers and cables with polyethylene (PE) insulation [4].

POLIM surge arresters for medium-voltage networks

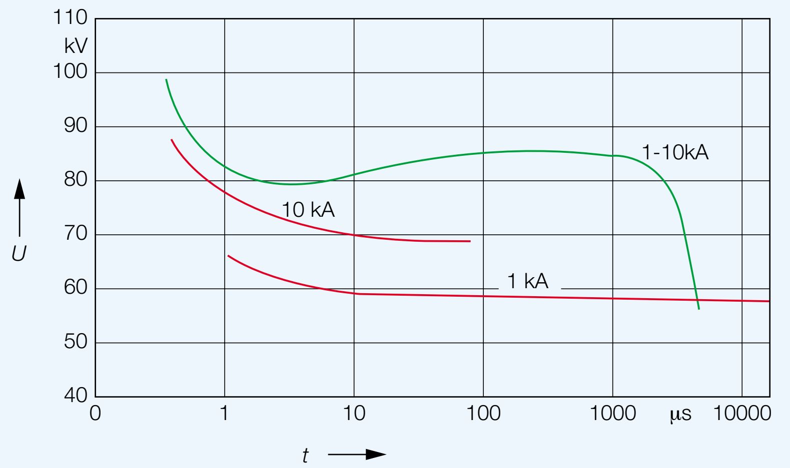
The main electrical data of the new POLIM arresters (POLIM comes from polymer limiter) and the first-generation MVK and MWK arresters are given in

Table 2. The technical data conform in each case to IEC 99.4 (1991) and ANSI C 62.11 (1993). These arrester families allow electric power utilities' requirements to be met in a optimum way.

Overview

Table 2 shows that the arresters can be divided into three groups as follows:

- Standard arresters for IEC class 1 and ANSI ('heavy-duty class') protection of distribution systems, represented by types MVK and POLIM-D. Certain electrical and mechanical guarantee values can differ. Arresters of this type are available with standard or, where longer creepage paths are required, alternated sheds.
- Arresters designed to satisfy stricter criteria, as per IEC class 2 or ANSI ('intermediate class'). Types MWK, MWD and POLIM-I belong to this category. They have almost the same guarantee values, but allow a choice of mechanical properties – for example, POLIM-I features a much increased bending moment, making this arrester the preferred choice for applications in which very high stressing is likely to occur. MWK arresters are available with standard sheds or alternated sheds. The type MWD is a typical indoor arrester without sheds.
- Arresters designed to meet the highest requirements (IEC classes 3 and 4 and the ANSI 'station class'). POLIM-S and POLIM-H satisfy these criteria. They combine an extremely high energy absorption capacity with a low protective level and high mechanical strength. Such arresters offer the properties of post or suspension insulators, and are specially well-suited for traction applications [5]. The family of POLIM medium-voltage arresters is shown in **2**.



Voltage-time characteristic of gapped and metal-oxide arresters for a nominal voltage of 24 kV **1**

Green *Sparkover voltage curve of gapped arresters*

Red *Residual voltage curves of MO arresters for lightning surge currents (10 kA, 8/20 µs) and switching surge currents (1 kA, 30/60 µs); protection is generally more economical with smaller currents due to lower residual voltages*

Design principles

ABB has based all of its surge arresters with polymer insulation on the same proven design concept, which it has also patented. The arresters consist of two electrodes, connected to each other

Table 1:
Comparison of metal-oxide and gapped surge arresters

MO surge arresters	Gapped arresters
• No sparkover, current flows as per *U-I* characteristic	• Sparkover, afterwards 50-Hz follow current
• Small scatter band for residual voltages, typically ± 3%	• Usual scatter band for spark gaps, possible influence due to non-linear voltage distribution, up to 15% scatter
• Good steep-front wave characteristics, eg only approx. 10% increase in residual voltage at 1/3 µs, current peak rises to 8/20 µs [2]	• Strong rise (>25%) in sparkover voltage due to steep-fronted surge voltages
• Temporary 50-Hz load above U_c possible	• Continuous voltage at 50 Hz, always lower than rated voltage
• Energy absorption capacity can be increased by connecting MO arresters in parallel	• Restricted energy absorption capacity, parallel connection without effect
• Simple active part with few components	• Complex structure for active part
• Negligible aging effect	• Aging of spark-gaps due to arc erosion or bead formation

Table 2:
Main technical data of medium-voltage arresters with silicone insulation

		MVK MVD	POLIM-D -N, -L	MWK MWD	POLIM-I	POLIM-S	POLIM-H
Continuous voltage U_c [1]	kV	to 38	to 24	to 44	to 44	to 44	to 44
Rated current 8/20 µs, I_n	kA	5/10	10	10	10	10	20
High-impulse current 4/10 µs, I_{HC}	kA	>65	100	100	100	100	>100
Rectangular wave 2 ms	A	250	250	550	550	1,000	1,350
Max. energy absorption during operating duty test per kV_{U_c}	kJ	to 2.5	to 4.2	to 5.5	to 5.5	to 9	to 13.3
Line discharge class	IEC	1	1	2	2	3	4[2]
Class/category	ANSI	Standard	Heavy duty	Intermediate	Intermediate	Station	Station
Mech. bending moment 100%, as per DIN 48113	Nm	350	250	350	2,500	4,500	6,000
Diameter of MO resistor	mm	38	38	47	47	62	75
Creepage: standard and alternated sheds		yes	yes	yes	alternating sheds as standard		

[1] U_c = Maximum continuous operating voltage (MCOV)
[2] High lightning surge current

by two or more fiber-glass-reinforced elements. This creates a relatively rigid and stable frame, inside which the metal-oxide resistors are mounted. The remaining space within the frame is taken up almost completely by cylindrical metal parts or metal plates. A thrust screw situated in the center of one of the electrodes is tightened from the outside and then secured in its end-position.

This assembly is then placed in a mould, into which high-temperature liquid silicone rubber is poured to form a monolithic arrester unit. **3** shows a POLIM-H arrester before and after the moulding process.

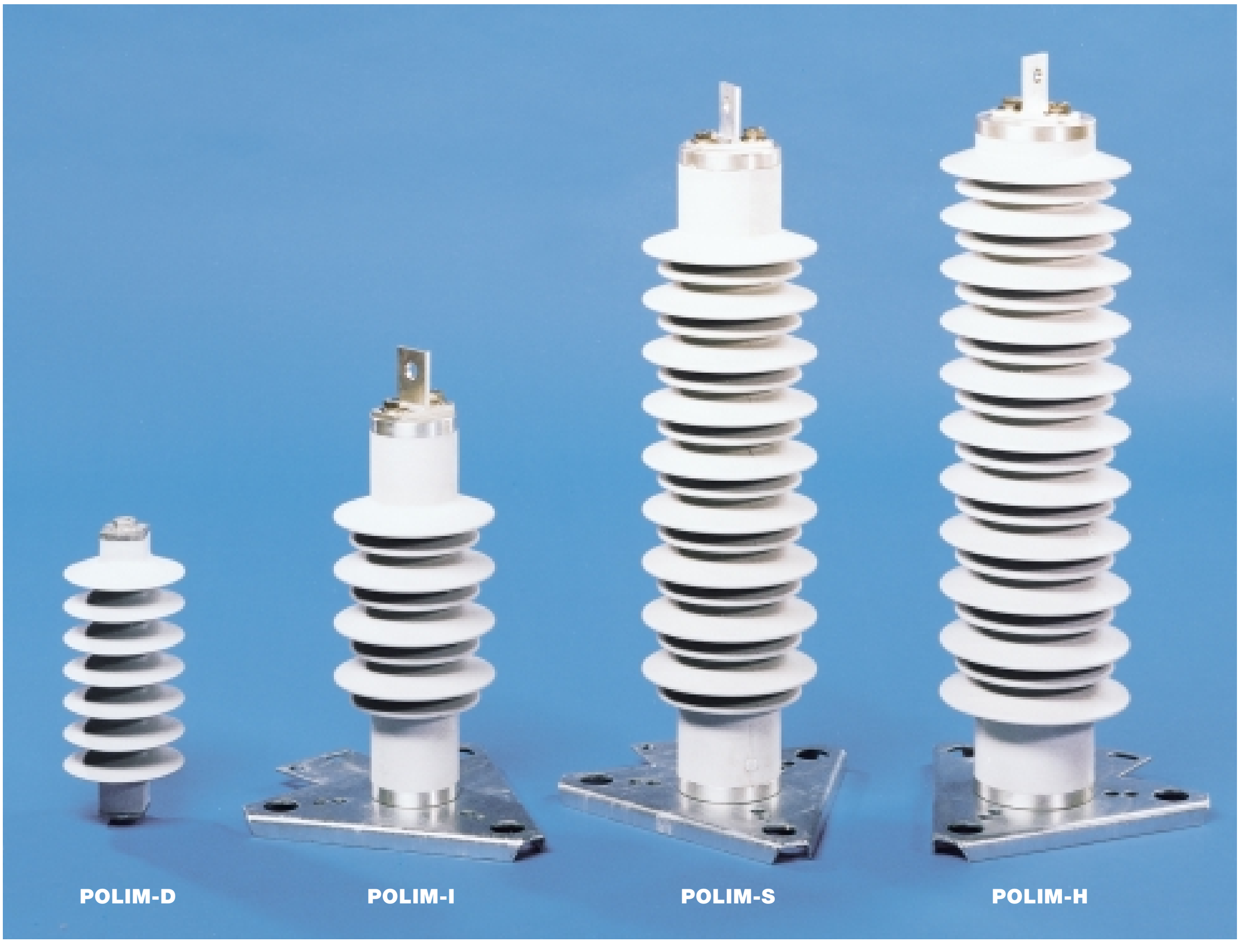
The many benefits of silicone rubber

Silicone rubber (usually referred to simply as 'silicone') is an excellent insulating material for high-voltage components. Comparisons with traditional insulating materials, such as ceramic, glass and other synthetics (eg, ethylene-propylene-diene monomer, or EPDM) show clearly the superiority of silicone. As already mentioned, during the manufacture of the surge arrester the silicone insulation is bonded to the arrester assembly through casting (or injection) of the liquid rubber in moulds at a high temperature. Different moulds can be used to obtain an optimum match between the insulator and the component assembly. The arrester insulator thus produced exhibits the following properties:

- No hydrocarbon is present in the main chemical chain **4**; this property is part of the reason for the insulator's high immunity to serious surface pollution and is also largely responsible for preventing carbonized creepage paths from forming.
- The material is water-repellent, so that even after excessive contact with water only very few drops adhere to the surface. This property is referred to in the industry as *hydrophobicity*. Drops of water that do cling to the surface are quickly removed by the effect of gravity or through normal exposure to wind.

The hydrophobicity effect is also partly transferred to any dirt deposits on the surface, which as a result does not become coated with layers of semiconducting material as quickly as other types of insulation. Because of this, the surface leakage currents flowing on silicone insulators are extremely low. The technical literature explains the transfer of the hydrophobicity effect to dirt deposits as being due to low-molar silicone evaporating.

The hydrophobicity effect is temporarily reduced by strong electrical partial



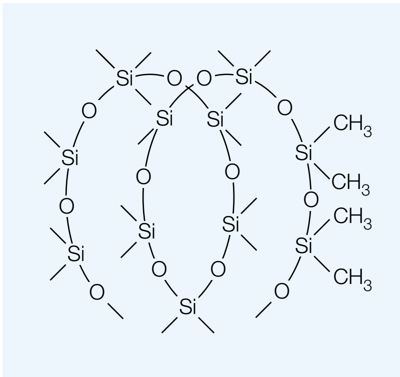
Family of POLIM medium-voltage arresters with silicone insulation **2**

POLIM-H surge arrester – on the left with silicone housing and on the right before bonding with the silicone in a mould **3** discharges or extreme exposure to water, but to a lesser degree with silicone than with other materials. This is clearly shown by the artificial aging of EPDM and silicone in accordance with IEC 1109 **5**. After 5,000 hours of alternated precipitation, salt-fog and UV radiation, the silicone still retains 50 percent of its water-repellent properties, whereas EPDM loses these properties. Tests have further shown that the hydrophobicity effect can be restored to its original state by drying the silicone for several hours.

The salt-fog test to IEC 507 also demonstrated that, assuming the same salinity in each case, the creepage paths required for silicone insulation are, on average, 30 percent shorter than the paths necessary with ceramic isolators **6**. As a result, the creepage path of the silicone isolators could be reduced by this amount.

The short-time tests to IEC 507 provide the basis for the insulator's dimensions. In certain cases, the insulator behaviour may deviate under actual field conditions as a result of other parameters (eg, due to the shape of the sheds). However, it is generally true for silicone as well as for the ceramic insulators that extreme pollution calls for a longer creepage path.

The mentioned temporary reduction in hydrophobicity was taken into account in the design of the POLIM arresters, and the specific creepage path was not reduced. All of the discussed surge arresters with silicone insulation have been designed with a specific creepage path of at least 25 mm per kV, providing a more than adequate safety margin. Whenever possible, all the pollution and lifetime tests were carried out on complete MO arresters. The tests were performed to the various standards (eg, the 1,000-hour humidity room test to IEC 1109, the 5,000-hour aging cycle test and the salt-fog test to IEC 507) and showed that the silicone insulation performs better after ten years in service than the other types of insulation.

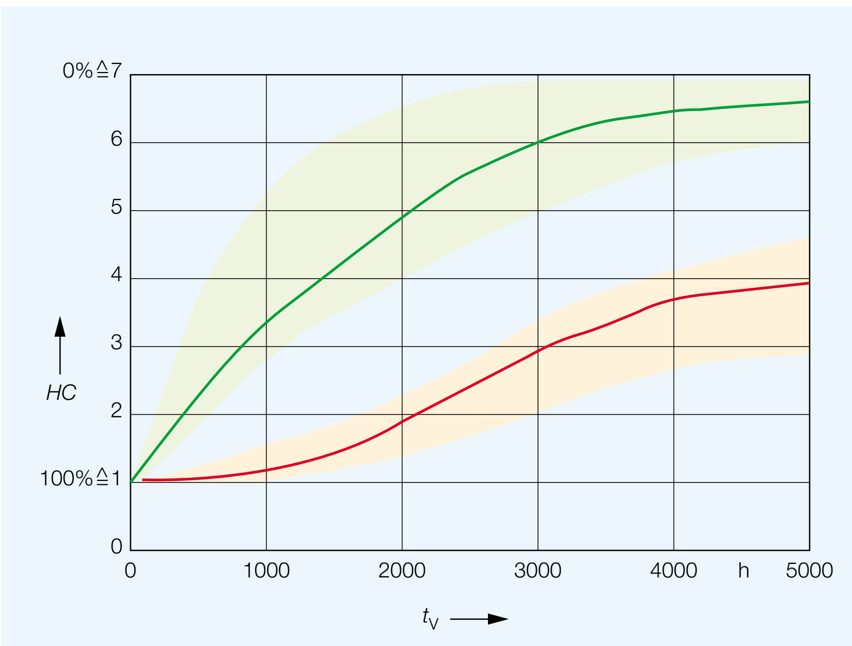


Silicone molecule – the main chemical chain is free of hydrocarbon **4**

Change in the hydrophobicity (water-repellent properties) of EPDM (green) and silicone (red) during artificial aging as per IEC 1109 **5**

HC Hydrophobicity

t_V *Test duration*



Type tests and operating experience

As mentioned, the type tests were generally carried out in conformance with IEC 99-4 (1991) and ANSI C 62.

These standards, which are valid at the present time, apply in the first instance to arresters with ceramic insulators. Standards for surge arresters with polymer insulators are being prepared. Tests on such arresters have, however, already been carried out in accordance with the draft standards (in the case of polymer arresters, IEC TC 37 WG 04).

In addition to the mentioned aging and pollution tests, extensive testing took place to determine the arresters' overload behaviour. This involved overload tests with a constant voltage and a constant current as well as tests on arresters with electrically defective active parts. The test method used allows an approximation of actual field conditions and can be performed in most test laboratories.

The overload test with a constant voltage simulates a so-called voltage 'overspill', in which the voltage of a power system operated at a higher voltage level flashes over to a power system at a lower voltage level. The sudden appearance of a voltage equal to 1.5 to 2 times the arrester's continuous voltage U_c results in the MO active part failing within a time that can be as long as several tens of seconds.

The overload test with a constant current of up to several 100 milliamps causes the arrester to heat up slowly until it becomes thermally unstable. The entire test can last from several minutes to an hour, depending on the applied current. A second high-power voltage source can be used to check the function of the pressure-relief system at the end of the test.

Tests with active parts that have been modified to simulate a defective arrester demonstrate what happens when power is applied to a unit which is already damaged as the result of an earlier overload.

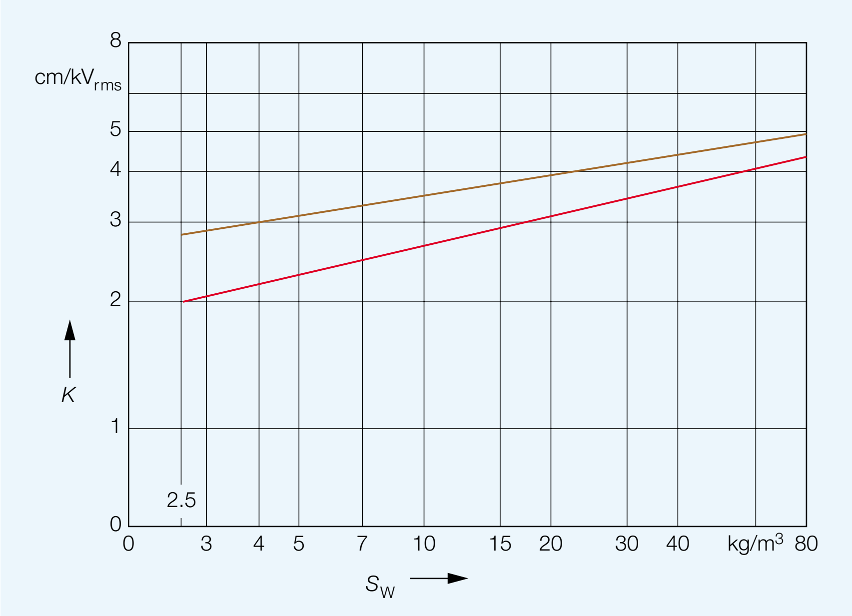
Overload and pressure-relief tests carried out on arresters with predrilled MO disks and/or an artificially short-circuited active part are performed to simulate a theoretically conceivable worst case. Since the arresters have to be prepared manually before testing, the results of these tests are less realistic than those obtained with an intact arrester which is subjected to a natural overload.

The result of a test under conditions similar to those existing in the field, carried out with a constant voltage at a current of 25 kA_{rms} (0.2 s), is shown in **7**. The arrester failure – during which no explosion occurred – is clearly visible. Many other tests with currents between 5 A and 63 kA_{rms} have proved that the arresters remain mechanically intact during pressure-relief tests, and that no disintegration or explosion takes place. The majority of the type tests were verified by neutral test institutes. Reports of these and all other tests performed on the arresters are available for inspection by customers.

Improved reliability for power supplies with modern arresters

The type MWK and MVK metal-oxide arresters with silicone insulation were introduced and patented by ABB some ten years ago. Field results with the arresters in the meantime have been excellent.

The same design principles were also adopted for the new POLIM arresters. Operating experience with these arresters to date has been excellent and promises continued reliable operation in the future. Reasons for the good performance of the POLIM arresters include the following:



Comparison of the specific creepage paths of ceramic (brown) and silicone insulators (red) as a function of the salinity during a salt-fog test to IEC 507 **6**

K Creepage path

S_W Salinity of water

POLIM-H surge arrester for a continuous voltage U_c of 24 kV after an overload test rated at 25 kA_{rms}, 0.2 s **7**

POLIM-H surge arrester with a continuous voltage rating of 44 kV, used as transformer protection in a switchyard in Switzerland **8**

- The direct bonding of the silicone insulation to the mechanically fixed metal-oxide body in a mould results in a compact, monolithic assembly exhibiting high operational reliability.
- The simple design of the arrester. There are no internal air-gaps, and the absence of air boundary layers prevents partial discharges and premature electrical aging.
- The silicone insulation, with its hydrophobicity effect, excellent resistance to UV rays and high dielectric strength in the presence of pollution, performs better than any other insulation under harsh environmental conditions.
- Silicone housings, unlike ceramic isolators, do not explode or disintegrate when the arrester is overloaded. Arcs cause holes to be burnt in the polymer housing, making an arrester which has blown out easily recognizable.
- A reduction in weight of 50 percent and the inherent flexibility of the silicone insulation make POLIM and MWK/MVK arresters easier and more economical to transport. There is no risk of the housing fracturing during erection work.

More than 80 percent of the surge arresters currently being supplied by ABB to the medium-voltage sector have silicone insulators. The trend towards polymer insulation and away from ceramic underscores the power industry's preference for the former **8**. Silicone has particularly important benefits for outdoor applications that call for high-quality insulation. Modern MO arresters with silicone insulation are therefore ideal for overvoltage limitation in electricity grids, where they make an important contribution to the safety and reliability of power supplies.

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