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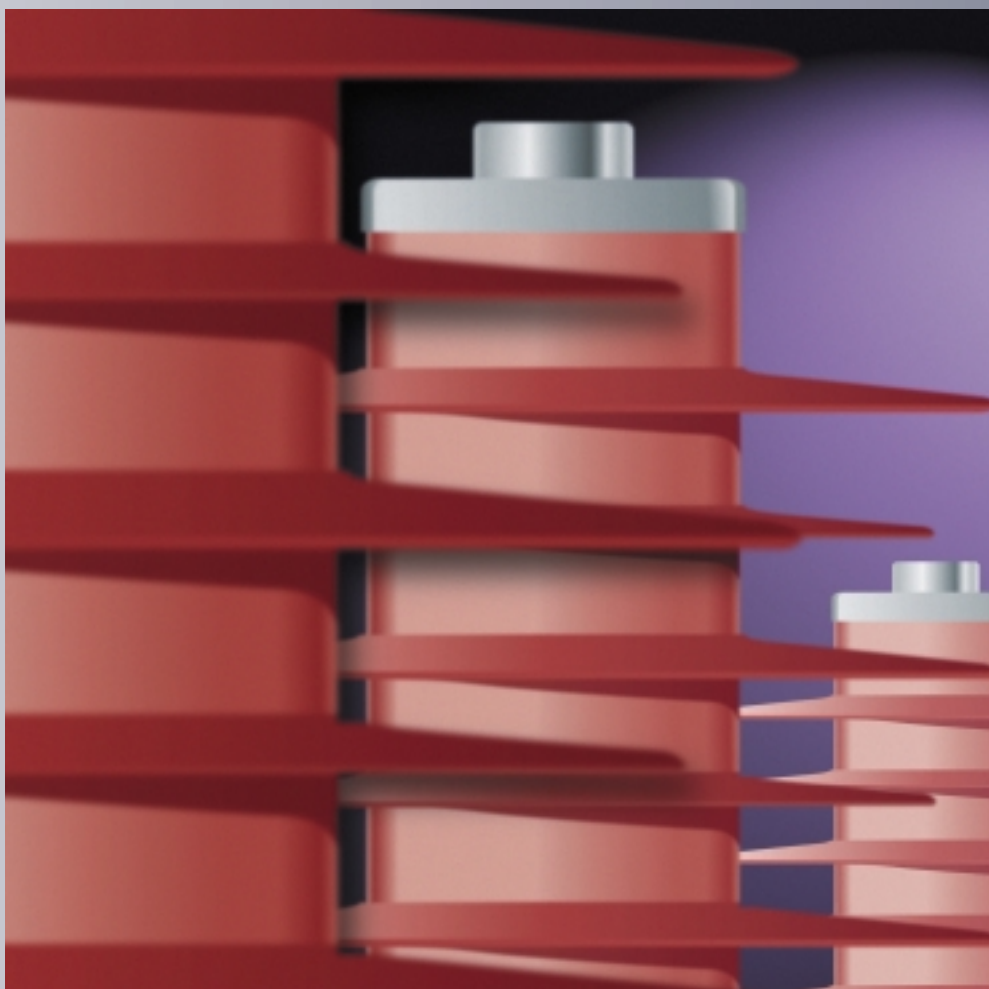
*Electronics*

***Energy Division***

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**MO Surge Arresters**

**Selection and Application in Medium Voltage  
Power Systems**



## 1. Introduction

## 2. MO medium-voltage arresters

- 2.1 Arrester design
- 2.2 Operation
- 2.3 Selection parameters

## 3. Selection

- 3.1 Effect of temporary overvoltages on the MO arrester
- 3.2 Significance of rated voltage  $U_r$  of the arrester
- 3.3 Arrester selection and determination of the continuous operating voltage  $U_c$
- 3.4 Examples and special cases
  - 3.4.1 Networks with earth fault compensation or high-impedance isolated neutral
  - 3.4.2 Networks with high-impedance isolated neutral and automatic earth fault clearing
  - 3.4.3 Networks with low-impedance earthed neutral  $E \leq 1,4$
  - 3.4.4 Networks with low-impedance earthed neutral  $E > 1,4$
  - 3.4.5 Surge arrester between phases (Neptune design)
  - 3.4.6 Operating voltage with harmonics

## 4. Protection

- 4.1 Protection level of an arrester
- 4.2 Protective zone of an arrester

## 5. Special applications

- 5.1 Overvoltage protection for cable section with overhead line transition
- 5.2 Transformer at the end of a cable
- 5.3 Transformer directly connected on one side only to a lightning-prone overhead line
- 5.4 Arrester on gas-insulated medium-voltage switchgear
- 5.5 Generator connected to a lightning-prone medium-voltage line
- 5.6 Overvoltage protection of motors
- 5.7 Cable sheath protection of high-voltage cables
- 5.8 MO arresters for DC voltages

## 6. Application consulting for arresters

## 1. Introduction

Equipment in electrical supply networks is exposed to many stresses. One of the major hazards is overvoltages. The high cost precludes machinery and equipment from being designed to withstand arbitrarily high voltages. The nature of the hazard generally means that it cannot be eliminated but reduced only. For these reasons, the approach usually followed is to build protective devices into the network. This has proved a cost-effective and reliable method for achieving economic and reliable network operation. This applies to both high- and medium-voltage networks and also to low-voltage networks.

The greatest risk to equipment through overvoltages comes from transient overvoltages. They are caused by atmospheric discharges and by switching operations. The use of over-voltage surge arresters is considered the most effective protection against these transient overvoltages. The arrester is installed in the immediate vicinity of the equipment to be protected and acts as bypath for the overvoltage impulse.

The magnitude of an overvoltage is mostly specified in the unit p.u. (per unit). This unit is defined as

$$1 \text{ p.u.} = \sqrt{2} \cdot U_m / \sqrt{3}$$

where  $U_m$  is the highest permissible voltage for the equipment, specified as the RMS value between the phases in normal network operation. The actual system voltage is usually less than  $U_m$ .

$U_m$ (kV)	3.6	7.2	12	17.5	24	36	42
1 p.u. (kV)	2.9	5.9	9.8	14.3	19.6	29.4	34.3

Table 1: Value of 1 p.u. for different  $U_m$

In addition to transient overvoltages, electrical networks also experience temporary over-voltages. As a rule, these power frequency overvoltages are produced by disturbances in the network. To summarize, overvoltages that occur in networks can be divided into the following categories:

### – Temporary power frequency overvoltages

These occur, eg, after a load dump or in the case of earth faults. Their duration can be between 0.1 seconds and several hours. Generally their amplitude does not significantly exceed  $\sqrt{3}$  p.u., so that they do not as a rule pose a threat to equipment. Nonetheless, they are a critical factor in the right choice of arrester.

Ferromagnetic resonance in the transformer can also lead to very high, mostly power frequency, overvoltages. Gapless arresters will prevent the transformer insulation from being damaged by those resonances. The arresters themselves, however, will be overloaded and thermally destroyed. Modern, low-loss transformers, connected under no-load via a single-ended cable section, are particularly prone to trigger ferromagnetic resonance that destroy the surge arresters.

### – Switching overvoltages

These occur frequently during switching operations and they usually exhibit a strongly damped, oscillating pattern. The frequency of the oscillation is often under a few kHz, and the crest value can go up to 3 p.u.

Steeper impulses with higher crest values can be measured during switching operations in predominantly inductive power circuits. Here the front time of the overvoltage can be in the range from 0.1 to 10  $\mu$ s and the crest value can go up to 4 p.u.

Connecting and disconnecting overhead lines or cables can also generate steep overvoltages. Since their crest value is generally below 2.2 *p.u.*, they are not considered a risk for network operation. Critical values up to 7 *p.u.* may, however, occur, if the disconnector is operating too slowly and back flashes occur.

In the widest sense, switching overvoltages also include transient overvoltages caused at the start of earth faults or short circuits in the network. In general, however, the amplitudes are rather small. On the other hand, if they occur in quick succession (intermittent earth faults), the frequent and repeated stress can lead to thermal overloading of gapless arresters.

#### **– Lightning overvoltages**

These are caused by atmospheric discharges. A direct lightning strike on an overhead line results in especially steep impulses with crest values of up to several Megavolts. These as a rule do not reach the equipment, because the insulators installed on the overhead line flash over, providing a type of natural overvoltage protection. In a medium-voltage network, the amplitude remaining after such an insulator flashover can still reach values up to 10 *p.u.*

A lightning strike in the vicinity of an overhead line also induces overvoltages in the conductors. These induced overvoltages reach their crest value after a few  $\mu\text{s}$  and then quickly decay again. Again, the crest values in medium-voltage networks are about 10 *p.u.* Lightning overvoltages are the most extreme form of overvoltage stress in medium-voltage networks. The job of the overvoltage arrester is to limit these to a value that can be tolerated by the equipment. At the same time, failure of the arrester, eg, through overloading, should not cause more than an unavoidable minimum of damage.

## 2. MO medium-voltage arresters

Almost all the new high-voltage networks installed in the past 15 years have used MO arresters. In medium-voltage networks, by contrast, a substantial number of conventional gapped arresters (SiC resistors and series spark gaps), were still being installed until only a few years ago. Today, MO (**M**etal-**O**xide) arresters without spark gaps have gained the upper hand here too. This change is justified, as in high-voltage networks, by an improved protection level, especially for very steep overvoltages, and better performance in a polluted environment. The change to polymeric housings made it possible to do without the previously necessary spark gaps. Polymeric housings also have other important benefits, such as greater reliability (tightness against moisture ingress!) and a significantly reduced risk in the event of arrester failure (violent shattering of the housing).

### 2.1 Arrester design

Basically, an MO arrester consists of just two elements. One is the active part, consisting of one or more stacked, usually cylindrical, MO blocks (resistor blocks). The second is the insulated housing. The arrester derives its mechanical strength either from the housing (eg, ceramic housing) or, in the case of polymeric housing, from the active part. In the latter case, there is usually a glassfibre structure that either completely encloses the resistor blocks or that exerts sufficient force on the ends of the stack to hold the MO blocks firmly together.

The simple and mechanically robust design of the active part and the reduced risk in the event of arrester failure, makes it possible to use some arresters with polymeric housing as stand-off insulators in certain cases.

### 2.2 Operation

An arrester limits the voltage applied to its terminals by forming a voltage divider together with the impedance of the overvoltage source or the characteristic wave impedance of the feed line. The resistance of the arrester is nonlinear, so that above a certain limit the voltage at the terminals increases proportionally less than the increase in the current. The greater the nonlinearity, the narrower the range of the residual voltage of the arrester.

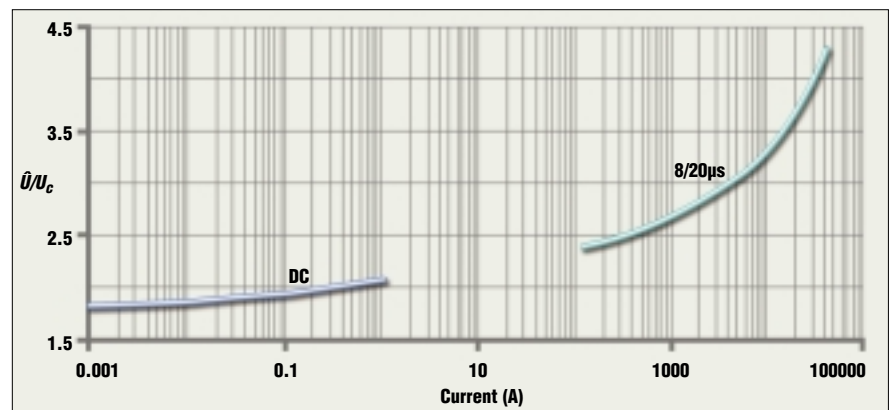


Fig. 1: Typical current-voltage characteristic of a 10 kA Class 1 MO arrester

Because MO arresters have no spark gaps and their nonlinearity is so great that under normal operating conditions only a very small resistive current component flows, the arrester passes into the conducting state continuously and practically without delay (depending on the U-I characteristic of the MO resistor block used). In other words, there is no delayed response, as there is with gapped arresters, where the spark overvoltage of the gaps must first be exceeded. This means that MO arresters have two big benefits. Firstly, the MO arrester reliably limits the voltage to low values, even for steep impulses and even at the start of the overvoltage impulse. Secondly, there is no way the amplitude of low switching impulses can "bypass" the arrester.

As the overvoltage decays, the discharge current decreases, in line with the characteristic of the MO block, so that no power follow current occurs. This is especially important in DC voltage systems, because here there is no natural zero-crossing of current that is needed to clear

the power arc of a spark gap if there is one. In principle therefore, MO arresters can be used in 50/60 Hz, 16 2/3 Hz and DC voltage systems, always assuming appropriate MO resistor block properties.

### 2.3 Selection parameters

Selecting an arrester means considering two main parameters. One is the continuous operating voltage  $U_c$ , under which the arrester will be expected to operate reliably and stably for many years. The other is the discharge handling capability, or the nominal discharge current  $I_n$  in conjunction with the line discharge class.

## 3. Selection

### 3.1 Effect of temporary overvoltages on the MO arrester

Because they lack spark gaps, the resistor blocks in MO arresters are continuously stressed by the power frequency voltage. Under normal operating conditions, the essentially capacitive current is overlaid by a very small resistive, non-sinus-shaped current component. This resistive component continuously generates losses in the arrester, with the result that the arrester heats up slightly relative to ambient temperature.

When the voltage rises, the resistive component and losses increase rapidly. However, thanks to its thermal mass, the arrester is not destroyed immediately, but instead heats up to a lesser or greater degree. If the stress caused by the temporary overvoltage falls to the normal acceptable level within a certain time, the arrester will probably not suffer permanent damage. The temporary overvoltage characteristic curves in Fig. 2 show how long a particular voltage can be withstood without thermal runaway occurring. In the lower curve, the arrester was previously subjected to high-energy impulses in addition to the pure overvoltage stress with  $U_{TOV}$  (in the case of 5 kA and 10 kA Class 1 arresters with a high-current impulse of the [form] 4/10  $\mu$ s and an amplitude of 65 kA or 100 kA). The second, upper curve shows the case where only the overvoltage stress occurred.

The values in the temporary overvoltage characteristic of an arrester are specified either as absolute numbers or with reference to the arrester's continuous operating voltage  $U_c$ .

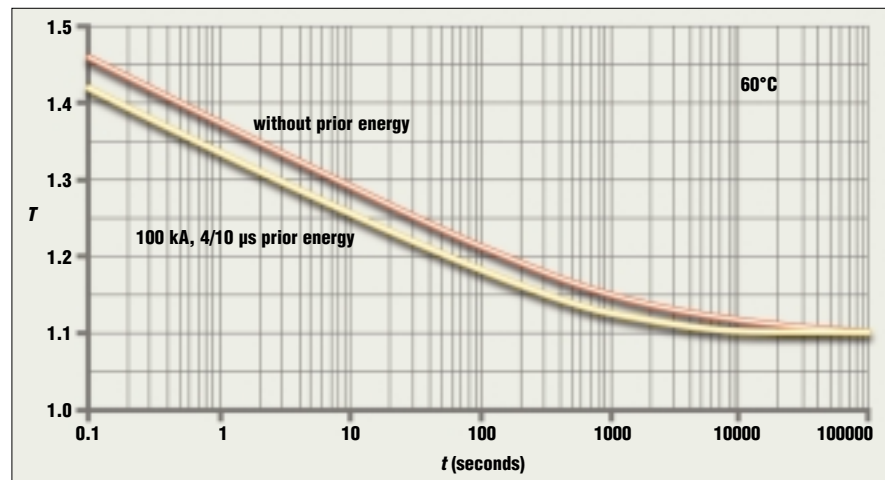


Fig. 2 : Temporary overvoltage characteristic, TOV diagram ( $T = \frac{U_{TOV, max}}{U_c}$ )

The following example explains the use of the diagram:

A 10 kA Class 1 arrester with a  $U_c$  of 6 kV is being operated with a voltage of 6 kV at its terminals for an undefined length of time. At time  $t = 0$  a discharge occurs whose energy conversion in the arrester corresponds approximately to a discharge current of 100 kA of the form 4/10  $\mu$ s. Immediately following the discharge, an earth fault occurs, so that the voltage of the healthy phases increases to roughly 7.7 kV ( $T = 7.7/6.0 = 1.28$ ).

The network's fault detection system is designed to clear a fault of this magnitude in under 3 s. The diagram shows that the arrester will just cope with this stress. Any delay in clearing the fault would mean that the point would lie above the lower curve, ie, the arrester would be thermally destroyed.

### 3.2. Significance of rated voltage $U_r$ of the arrester

The rated voltage  $U_r$  has no particular practical significance for the user, because its value depends heavily on the test conditions defined in the operating duty test according to IEC 60099-4. The rated voltage serves merely as a reference value for the definition of the operating characteristics.

### 3.3. Arrester selection and determination of the continuous operating voltage $U_c$

The first value required to set a continuous operating voltage  $U_c$  for the arrester is the voltage applied at the arrester terminals during normal operation. It makes a difference whether the arrester is connected between phase and earth, between the phases or between neutral and earth. Usually, the voltage can be calculated from the maximum system voltage between the phases. If this voltage is not known or if it changes in the course of time, the highest voltage for the equipment  $U_m$  should be used in the calculation.

In three-phase systems, temporary operating overvoltages can occur after earth faults whose magnitude is determined by the neutral earthing. The duration of the overvoltage depends on the [network operation]. [Solidly] earthed networks are usually switched off within a matter of seconds. Isolated and compensated networks can keep operating under conditions like these for several hours. The magnitude of the expected temporary overvoltage is often defined using the earth fault factor  $E$ . The temporary overvoltage  $U_{TOV}$  is then calculated as:

$$U_{TOV} = \frac{U_m}{\sqrt{3}} \cdot E$$

where  $U_m$  can be replaced by the system voltage  $U_s$  if this value is reliable.

If the MO arrester is to operate satisfactorily in the network, two conditions must be met when selecting the continuous operating voltage  $U_c$ :

- $U_c$  must be greater than or equal to the continuous operating voltage applied to the arrester terminals. For arresters connected to earth, the following condition applies:

$$U_c \geq \frac{U_m}{\sqrt{3}}$$

where  $U_m$  can be replaced by the system voltage  $U_s$ .

- The stress of the arrester subjected to temporary overvoltages must lie below or on the temporary overvoltage characteristic curve. As a check, the maximum duration of the temporary overvoltage should be specified as well as the magnitude. For safety reasons, always use the lower of the two curves, unless there are excellent reasons for doing otherwise. If the operating point lies above the curve, the arrester in question cannot be used in this network. Instead an arrester with a higher continuous operating voltage must be used.

$$U_c \geq \frac{U_{TOV}}{T}$$

where  $T$  is determined by the system clearing time  $t$  and the temporary overvoltage characteristic.

### 3.4 Examples and special cases

#### 3.4.1 Networks with earth fault compensation or high-impedance isolated neutral

In these networks, the conductor-earth voltage of the healthy phases not affected by the earth fault will generally not exceed  $U_m$ .

$$U_C \geq U_m$$

for arresters between phase and earth

The maximum voltage at the transformer neutral is the value  $U_m/\sqrt{3}$ :

$$U_C \geq \frac{U_m}{\sqrt{3}}$$

for arresters between transformer neutral and earth

It must be noted, however, that the earth fault factor  $E$  can reach a value of 1.85 under certain circumstances as a result of resonance phenomena. In such cases the continuous operating voltage  $U_C$  must be increased accordingly.

#### 3.4.2 Networks with high-impedance isolated neutral and earth fault clearing

Here the magnitude of temporary overvoltages is the same as in networks with earth fault compensation. Rapid clearing, however, may mean that an arrester with a lower continuous operating voltage  $U_C$  and therefore a better protection level is suitable.

$$U_C \geq \frac{U_m}{T}$$

for arresters between phase and earth

$$U_C \geq \frac{U_m}{T \cdot \sqrt{3}}$$

for arresters between transformer neutral and earth

#### 3.4.3 Networks with low-impedance earthed neutral $E \leq 1,4$

Provided a sufficient number of transformers have low-impedance earthed neutrals, the earth fault factor will not exceed the value 1.4 for the whole network. Because of the large earth fault or short circuit current, clearance in such networks is very rapid, so that here too an arrester with a lower continuous operating voltage  $U_C$  and therefore a better protection level can be chosen.

$$U_C \geq \frac{1,4 \cdot U_m}{T \cdot \sqrt{3}}$$

for arresters between phase and earth

The maximum voltage at the neutral of unearthed transformers is

$$U_{TOV} = 0,4 \cdot U_m$$

$$U_C \geq \frac{0,4 \cdot U_m}{T}$$

for arresters between transformer neutral and earth

#### 3.4.4 Networks with low-impedance earthed neutral $E > 1,4$

If the transformer neutrals are earthed via an impedance to limit the earth fault or short circuit current to low values, the voltage in the healthy phases rises up to  $U_m$ . In the case of a purely resistive earth the voltage may even increase by up to 5% above  $U_m$ .

$$U_C \geq \frac{1,05 \cdot U_m}{T}$$

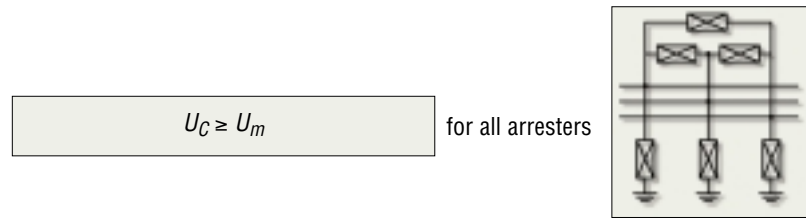
for resistive earth



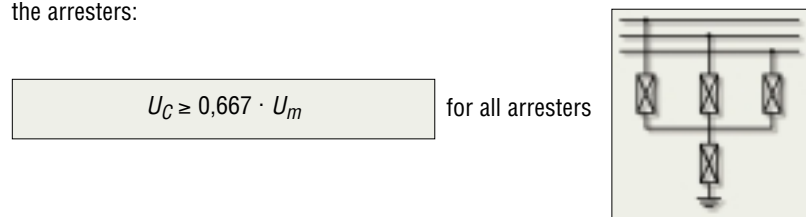
### 3.4.5 Surge arrester between phases (Neptune design)

In certain applications, such as transformers for arc furnaces, switching overvoltages occur where the level of protection provided by a conventional arrester configuration to earth is inadequate. In these applications, the protection level can often be improved by installing additional arresters between the phases.

The protection consists of 6 arresters, 3 between the phases and 3 between phase and earth:



A variation of this configuration is the Neptune design, so called because of its appearance. This design also offers protection both between the phases and to earth. The difference is a 33% higher protection level over the variant with 6 arresters. The reason for the higher protection level is that a relatively high continuous operating voltage  $U_C$  must be selected for the arresters:



### 3.4.6 Operating voltage with harmonics

Because of the nonlinear  $U-I$  characteristic, the critical value for MO arresters is the crest value of the operating voltage. If high voltage distortion, ie, high harmonic content, has to be taken into account in a network, the crest value of the voltage can deviate quite significantly from  $\sqrt{2}$  times the RMS value. Provided the deviation is under 5%, the value of the continuous operating voltage can be adjusted accordingly. For larger deviations, the arrester should be chosen in consultation with the arrester manufacturer.

The same applies to the use of MO arresters in the vicinity of SCRs. Commutation steps, commutation spikes and steady components may mean that additional selection criteria must be taken into consideration.

## 4. Protection

### 4.1 Protection level of an arrester

The protection level  $U_{res}$  is defined as the maximum residual voltage at the terminals of an arrester when a nominal discharge current of the form 8/20  $\mu$ s flows through the arrester. Most arresters installed in medium-voltage networks have a nominal discharge current of 5 kA or 10 kA. The form of the nominal discharge current is defined as 8/20  $\mu$ s, characteristic of an overvoltage impulse such as generated by a lightning discharge. Data sheets usually show the residual voltage for lightning current impulses and for multiples and fractions of the nominal discharge current.

Switching overvoltages have far lower amplitudes than lightning overvoltages. That is why the maximum residual voltages for switching impulses of the form 30/60  $\mu$ s are of interest. These are also specified in the data sheets for different amplitudes, eg, 125 A and 500 A.

### 4.2 Protective zone of an arrester

Overvoltage impulses on overhead lines and cables take the form of travelling waves. This means that voltages in a conductor at any given time depend not only on the time but also on the position along the conductor where they are measured. Voltage differences can be very large, especially in the vicinity of locations where the conductor impedance changes (eg, at the transition point of an overhead line or at a branch point). The reason for this are reflections at these so-called reflection points. The relevance for arrester applications is that the voltage stress on an item of equipment is not always the same as the residual voltage that being applied to the arrester at a given point in time. The further away the arrester is from the equipment, the greater this difference is likely to be. Beyond a certain distance, it can be assumed that the arrester offers no protection at all to the equipment. This critical distance is called the protective zone of an arrester. The arrester must always be positioned so that the electrical distance between the equipment and the arrester is smaller than the protective zone.

In medium-voltage systems the protective zone  $L$  of an arrester can be roughly estimated by the following formula:

$$L = \frac{v}{2 \cdot s} \cdot \left[ \frac{BIL}{1,2} - U_P \right]$$

where  $v$  = 300 m/ $\mu$ s (speed of light)  
 $BIL$  = basic impulse level of the equipment to be protected  
 $U_P$  = protection level of arrester (residual voltage at nominal discharge current)  
 $s$  = steepness of the overvoltage impulse

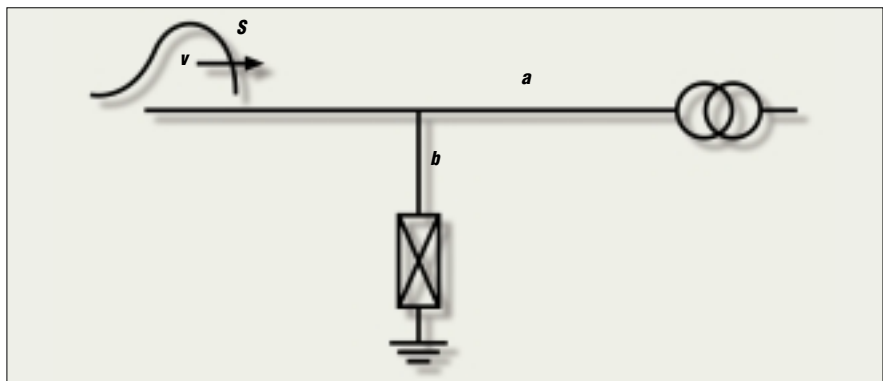


Fig. 3: Schematic arrangement of an overvoltage arrester

Typical values of  $S$  are 1550 kV/μs (for overhead lines on wooden poles) and 800 kV/μs (for overhead lines with earthed crossarms). For medium-voltage networks, these values result in roughly the following protective zones:

$L = 2,3$  m overhead lines with wooden poles

$L = 4,5$  m overhead lines with earthed crossarms

In the simplified arrangement in Fig. 3, the sum of the partial distances  $a$  and  $b$  must not exceed the protective zone  $L$ :

$$a + b \leq L$$

The calculation assumes that the earth lead connection of the arrester is so short that it can be ignored. If this is not the case, the distance must be added to the partial distance  $b$ .

In practice, the effect of transformer capacitance on the protective zone cannot simply be ignored. The capacitance can sometimes lead to a dramatic decrease in the protective zone  $L$ ; depending on the partial distance  $b$ , this can be as much as 80%. This is especially serious for overhead lines carried on wooden poles. For instance, up to a system voltage of 24 kV, the partial distance  $b$  is not more than about 1 m. The protective zone  $L$  is still about 2 m, leaving 1 m for partial distance  $a$ . For a system voltage over 24 kV, the maximum length of the partial distance  $b$  is only 0.6 m.

It is clear that the protective effect of an arrester is critically dependent on its position and on the arrangement of the conducting lines. For maximum protection, the arrester should be installed as close as possible to the equipment it is protecting and the overhead line should be connected directly to the arrester. Fig. 4 shows three connection variants for an arrester intended to protect a transformer. The third variant is the best, although it could still be improved by shortening the distance between the transformer and arrester. The first variant is the poorest, because it is obvious that the protective effect of the arrester could be sharply improved without much effort.

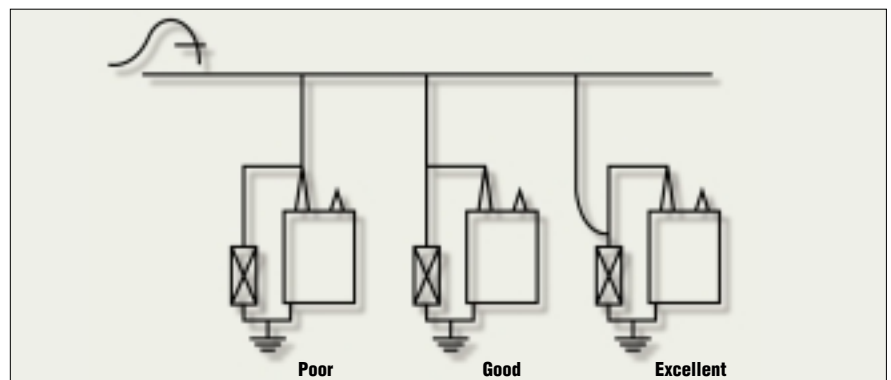


Fig. 4: Arrester configurations variants for transformer protection

In some cases, it may be very difficult, or even impossible, not to exceed the maximum partial distance  $b$  of 1 m or 0.6 m for overhead lines on wooden poles. In these cases, it may help to change the line configuration. As a rule, it is only necessary to earth the crossarms of the last 3 poles before the transformer. This reduces the steepness of the overvoltages enough to make the protective zone adequate. The disadvantage of this solution is that the average number of earth faults and short circuits in the system tends to increase, becoming nearly as high as in systems with earthed crossarms. Another, more elegant solution is to install another set of arresters on the last pole before the transformer, instead of additional earth connections. This also reduces the steepness of the overvoltages, but without increasing the number of earth faults or short circuits.

## 5. Special applications

### 5.1 Overvoltage protection for cable sections with overhead line transition

In most cases, it is essential to protect both ends of a cable section with arresters. For very short sections it may be sufficient to protect the cable at one end only.

A cable connecting an overhead line to a substation is really only at risk from overvoltages coming from the overhead line. The arresters must therefore be placed at the transition from the overhead line to the cable. A second arrester at the other end of the cable is not necessary, provided the cable length  $L_K$  does not exceed the values listed in Table 2. On the other hand, equipment inside the substation connected to the end of this short cable could be at risk from reflections at the cable end. This may make it necessary to install an arrester at this end of the cable as well.

$U_m$ (kV)	$L_K$ (m)	
	Wooden pole	Earthed crossarm
$Z$ ( $\Omega$ )	30	60
3,6	$\infty$	$\infty$
7,2	64	45
12	40	30
17,5	25	21
24	28	23
36	22	20

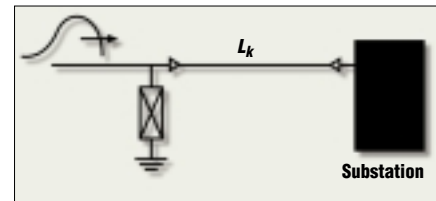


Table 2: Max. length  $L_K$  of a cable between a substation and overhead line with single arrester protection only

For optimal protection of the cable terminations and to minimize travelling wave phenomena, the arresters must be installed close to the cable terminations. All cables connecting to the arrester (including earth connections!) should be kept as short as possible for the lowest possible voltage in the conductor loops. The cable sheath or screen must be connected to the earth connection of the arrester.

For cables installed between two overhead line sections it may also be sufficient to install an arrester at one side only, even though overvoltages may enter from both sides. The protection offered by the arrester against overvoltages entering from the unprotected side is very much reduced, so that this solution can only be considered for very short lengths of cable.

If the cable is installed as part of an unearthed overhead line on wooden poles (see Table 3), the protective zone is extremely small. In this type of configuration, the "natural overvoltage protection" (see above) offered by insulators in the case of a direct lightning strike is very limited. The values for  $L_K$  listed in the table apply to arresters with a nominal discharge current of  $I_n = 10$  kA, provided that the high frequency impedance is constant along the whole cable section. Cable branches and other reflection points result in a further shortening of  $L_K$  to allow for reflections.

$U_m$ (kV)	$L_K$ (m)	
	Wooden pole	Earthed crossarm
$Z$ ( $\Omega$ )	30	60
3,6	7	3
7,2	9	4
12	9	4
17,5	6	3
24	10	5
36	8	4

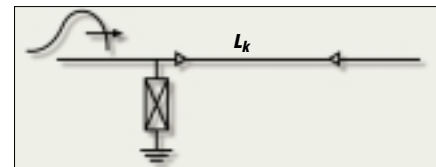


Table 3: Max. length  $L_K$  of a cable between two overhead line sections with one-sided protection (connecting length between arrester and cable max. 1 m)

## 5.2 Transformer at the end of a cable

If the length  $L_K$  of a cable exceeds the values given in the tables, a second arrester is required. The next question is to what extent the second arrester  $A_2$  will protect the downstream transformer. Here too, the distance between the arrester and the transformer is decisive.

In the following example, a transformer is again connected to an overhead line, susceptible to lightning strike, via a cable with a length  $L_K$  of over 100 m. As explained above, an arrester is required at both the overhead line transition and the end of the cable. The arrester  $A_1$  serves as protection for the conductor side, the arrester  $A_2$  limits the overvoltages caused by reflection at the cable end. The arresters are connected directly to the cable terminals.

$U_m$ (kV)	$a$ (m)			
	Wooden pole		Earthed crossarm	
$Z$ ( $\Omega$ )	30	60	30	60
3,6	300	300	500	500
7,2	43	37	53	53
12	20	14	20	14
17,5	17	10	16	10
24	19	12	19	12
36	16	11	20	11

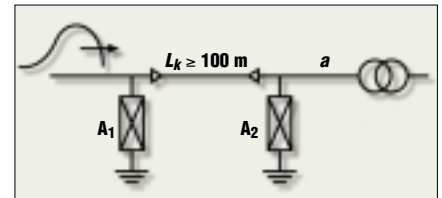


Table 4: Max. permissible distance  $a$  between cable end and transformer when the second arrester is installed directly at the cable end

In this installation, provided the distance  $a$  does not exceed the values listed in Table 4, the transformer will be adequately protected by the arrester  $A_2$ . The transformer capacitance is assumed to be 2 nF. Smaller capacitance values will increase the max. permissible distance.

## 5.3 Transformer directly connected on one side only to a lightning-prone overhead line

In general, only transformer connections that are linked to overhead lines with a risk of lightning strike need arrester protection against overvoltages. A different case is a high-voltage transformer that links a high-voltage network with a medium-voltage network, where only the high-voltage network is considered to be at risk of lightning strike. Under certain circumstances, an overvoltage protection on the medium-voltage side may also be necessary. Because lightning overvoltages are very fast processes, about 40% of the original overvoltage amplitude is also transferred capacitively to the medium-voltage side of the transformer. To limit this problem, the relevant regulations require a long cable, or a low-impedance capacitor, or a combination of these two on the medium-voltage side. An alternative solution using arresters has two clear advantages:

- Inductively transferred overvoltages may be increased by capacitors. Limiting the magnitude of the additional voltage stress requires carefully selected series damping resistors. In a solution using gapless arresters, this effect does not even have to be considered.
- A dielectric breakdown between one of the primary windings and the secondary windings of the transformer will subject equipment connected on the medium-voltage side to the high-voltage power frequency. If arresters have been installed to protect the medium-voltage side, these will be destroyed within a very short time and a short circuit will occur. The arrester "sacrifices" itself to protect the downstream equipment and most of the damage will be limited to the transformer. Because arresters are in fact designed to be destroyed, for whatever reason, the repercussions of this sacrifice are usually less serious than the destruction of other devices such as capacitors.

The superior protection offered by arresters is especially obvious in the case of a transformer linking a high-voltage network with a generator.

Similar considerations apply to a medium-voltage/low-voltage network connection. Here too, lightning overvoltages are transferred by the transformer capacitively from the medium-voltage network to the low-voltage side. This is why overvoltage arresters on the low-voltage side are recommended, even if only the medium-voltage side is at risk of lightning strike.

Whether and to what extent low-voltage arresters can protect a transformer at risk of lightning strike on the low-voltage side only is controversial. Many specialists are of the opinion that this protection is perfectly adequate. Time and again, however, there are reports of transformer failures that can be traced to lightning overvoltages on the low-voltage side. What is assumed to happen in these cases is that relatively slow, transient overvoltages on the low-voltage side are transferred inductively onto the medium-voltage side according to the turns ratio of the transformer, where they then puncture the insulation. In regions with a high lightning strike density it is therefore advisable to install arresters on both sides, even if only the low-voltage side is considered to be at risk.

#### 5.4 Arrester on gas-insulated medium-voltage switchgear

Special indoor arresters, installed close to the cable terminations, are usually used to protect gas-insulated medium-voltage switchgear. If the substation cell is connected with an overhead line at risk of lightning strike, the nominal discharge current of these arresters should be 10 kA Class 1. This applies even if a 10 kA arrester is already installed at the transition point between the overhead line and the cable. If the cable section is long, a 5 kA arrester in the substation could be considered, because the expected residual discharge current will diminish with the length of the cable and the arrester at the transition point will take the greater part of the discharge current.

If the arrester is only required to limit switching overvoltages, as in pure cable networks for example, a 5 kA arrester is generally adequate, because the expected discharge currents are relatively small.

The minimum clearances specified by the manufacturer between arresters, and between arresters and earthed components, must be maintained. Any change should only be approved after thoroughly testing the insulation withstand capability of the new configuration.

#### 5.5 Generator connected to a lightning-prone medium-voltage conductor

If a generator under load is abruptly disconnected from the network, the generator voltage will immediately rise sharply, until the voltage regulator acts to readjust it. The ratio of this temporary overvoltage to the normal operating voltage is the load dump factor  $v$ . Values up to 1.5 can be reached. The response time  $t$  is frequently between 3 and 10 s. The continuous operating voltage  $U_C$  of the arrester is therefore selected on the basis of these two values as described in Chapter 3.3.

$$U_C \geq \frac{v \cdot U_m}{T}$$

für Ableiter zwischen Phase und Erde.

#### 5.6 Overvoltage protection of motors

If high-voltage motors are switched off during run-up they are at risk from overvoltages on account of multiple re-ignitions in the switch. The re-ignitions occur most frequently if the current at switch-off is under 600 A. To protect the motors, overvoltage arresters must be installed directly at the motor terminals or, alternatively, at the circuit breakers. The arresters should be selected according to the recommendations outlined in section 3.

#### 5.7 Cable sheath protection of high-voltage cables

For thermal reasons and to reduce losses along a cable, the cable sheath or screen of high-voltage single-core cables is mostly earthed at one end only. The unearthed end must then be protected with arresters against transient overvoltages.

The critical selection criterion for the arrester is the voltage  $U_i$  induced along the cable in the event of a short circuit. This voltage depends on cable geometry and how it is laid in the cable duct, but it generally does not exceed 0.3 kV per kA short-circuit current and km cable length.

The operating point derived from the magnitude of the induced voltage  $U_i$  and the time interval  $t$  before the short-circuit current is switched off, must lie below the temporary overvoltage characteristic to ensure that the right arrester is being used.

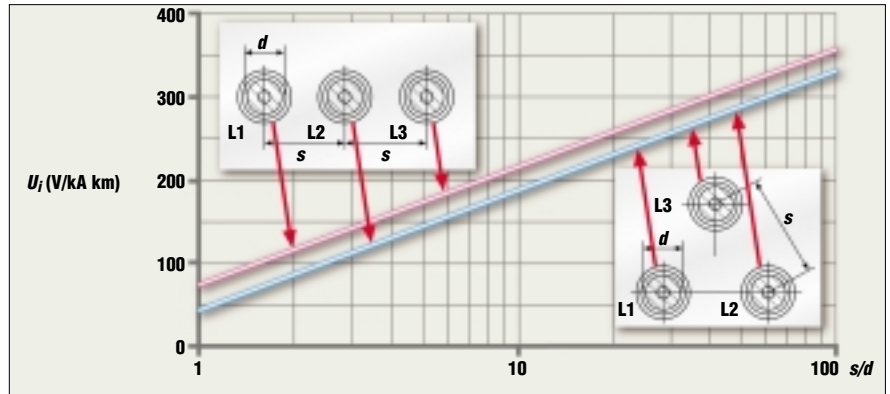


Fig. 6: Induced voltage  $u_i$  in the cable sheath or screen per kA short-circuit current and km cable length depending on the geometry

$$U_C \geq \frac{U_i}{T} = \frac{u_i \cdot I_k \cdot L}{T} \quad \text{for arresters between sheath or screen and earth}$$

where  $I_k$  is the max. short-circuit current and  $L$  the length of the unearthed cable section.

### 5.8 MO arresters for DC voltages

In DC voltage networks, lightning strikes or switching operations also cause overvoltages that may endanger machines and equipment. To date, no international standard or directive on the deployment of overvoltage arresters has been published. Nonetheless, arresters can be used successfully in such networks to protect equipment. Gapless MO arresters are ideal, because they do not pose the problem of clearing the power follow current caused by the DC voltage after a transient voltage stress, that usually has to be cleared with a relatively big effort.

Because of the different type of stress on the resistor blocks, arresters designed for AC voltage systems cannot simply be used in DC voltage systems. It is of the utmost importance that the use of a particular arrester in a DC voltage system is explicitly sanctioned by the manufacturer. The manufacturer must be consulted regarding dimensioning of the arrester.

## 6. Application consulting for arresters

Many discussions with users have confirmed that they would welcome intensive consulting on the use of overvoltage arresters. A typical case where expert support can be crucial is a planned technology change, eg, from spark-gap arresters with ceramic housings to MO arresters with polymer housings. Correct dimensioning of arresters when existing plant is being upgraded is another case in point. New applications, eg, in DC voltage networks or concept development for overvoltage protection of complete systems often require in-depth analysis of both the starting situation and requirements.

We therefore offer our customers consultancy services and comprehensive support on all questions of overvoltage protection. The scope of this document makes it difficult to do more than outline the factors that need to be taken into account.

All of the above information, including drawings, illustrations and graphic designs, reflects our present understanding and is to the best of our knowledge and belief correct and reliable. Users, however, should independently evaluate the suitability of each product for the desired application. Under no circumstances does this constitute an assurance of any particular quality or performance. Such an assurance is only provided in the context of our product specifications or explicit contractual arrangements. Our liability for these products is set forth in our standard terms and conditions of sale.  
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