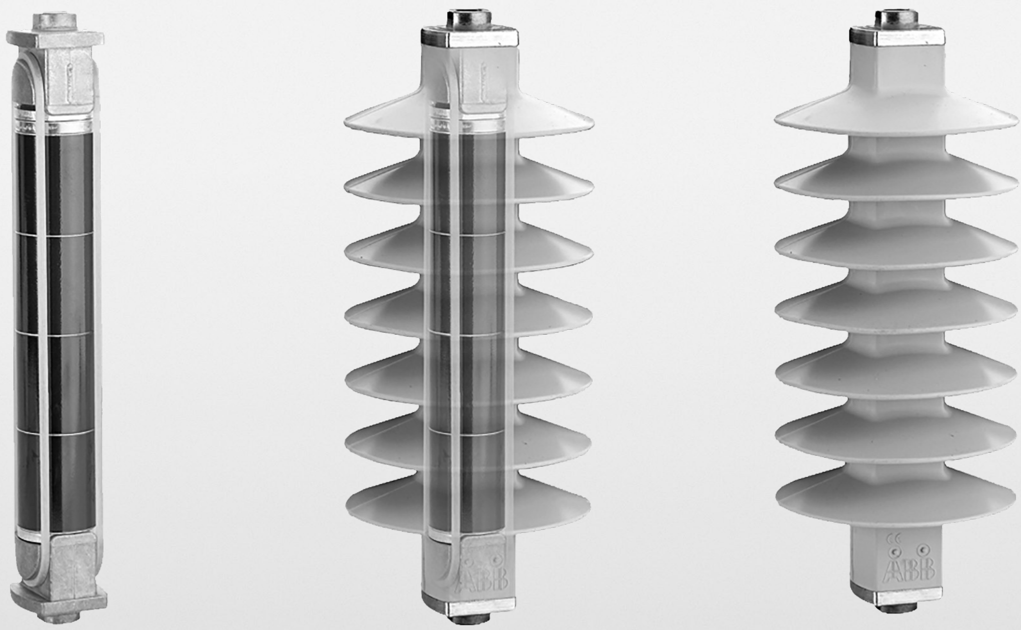
HITACHI ABB

APPLICATION NOTE 3.1

Cable sheaths

Overvoltage protection



The APPLICATION NOTES (AN) are intended to be used in conjunction with the

APPLICATION GUIDELINES
Overvoltage protection
Metal-oxide surge arresters in medium-voltage systems.

Each APPLICATION NOTE gives in a concentrated form additional and more detailed information for the selection and application of MO surge arresters in general or for a specific equipment.

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Overvoltage protection of cable sheaths

Cable sheath protection is a special but important field of the cable protection in general.

1 Introduction

High-voltage and medium-voltage cables are usually provided with a metal screen, which in turn is provided with an insulation against the surrounding. This outer insulation provides an electrical and a certain mechanical protection for the cable.

Single-core high voltage cables are normally provided with an outer concentric conductor, generally referred to as the metal screen which surrounds the current carrying conductor and insulation. The metal screen can be in the form of a sheath (welded or extruded), wires, tapes, or a combination thereof. Metal sheaths have the added benefit of providing a radial water barrier, avoiding water ingress and corrosion. Overvoltage impulses can perforate the outer insulation (jacket), which leads to water ingress and consequently to water treeing and electrical treeing, which is critical in case of sheaths made of wires. **Figure 1** shows as example a simple high-voltage (HV) cable.

When single-core cables carry power frequency a.c. currents, voltages are induced in the metal sheaths and currents flow along the metal sheaths if they are connected to form a closed circuit by earthing the metal sheaths at both ends of the cable. These sheath currents cause additional power losses in the cable. The additional power losses lead to an increased temperature in the cable and consequently to a reduction of the cable current rating. Metal sheath bonding methods have therefore been developed to ensure the cable sheaths are bonded and earthed in such a way to eliminate or reduce these longitudinal sheath currents. Sheath bonding methods to eliminate or reduce sheath currents are economical desirable, as the reduction in sheath current losses for cable circuits allow an appreciable smaller conductor size to be used (or conversely an increase in the current rating of the same cable) and lower energy losses to the cable system operator.

Sheath voltage limiters (SVLs) are surge arrester devices that are connected to the cable metal sheaths in the bonding systems. They are required to protect the sheath insulation, sectionalizing interruption at joints, GIS insulation flanges, and other accessories against overvoltages on the metal sheaths during system transients. State of the art and most widely used are gapless MO surge arresters due to the fast response to transients, compact design, and recovery after temporary overvoltages with power frequency (TOV).

In the following the different ways of cable laying, bonding principles, voltages and currents and measure taken for protection against overvoltages are described briefly.

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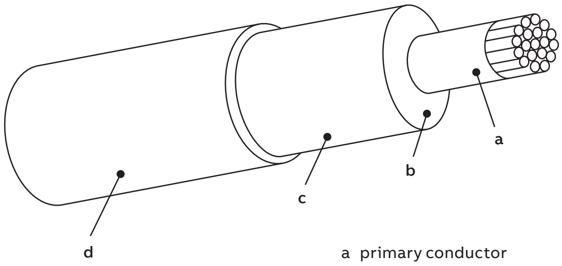
Figure 1: Example of a high voltage cable with metal sheath (principle)



a primary conductor
b primary insulation
c metallic sheath
d outer insulation (jacket)

2 Bonding schematics

2.1 General

Depending on the system voltage different bonding principles exist. Solid-bonding design is typically used on medium-voltage (MV) systems (up to 66 kV). On high-voltage (HV) systems and extra-high-voltage (EHV) systems solid-bonding is not commonly used except for a few countries and except on submarine cables where no other alternatives exist. Sectionalized cross-bonding design is the most used for HV and EHV cables except on short cables where single-point bonding is mostly used.

Figures 2 and 3 show examples of sheath bonding configurations for the identification of bonding leads, grounding leads and earth continuity conductors (ECC). Bonding leads are insulated conductors connecting the metal sheath and the bonding connections within link boxes. Grounding leads are also insulated conductors connecting link boxes with earth or the termination ground.

Link boxes provide housing for bonding and earthing connections. They may also contain SVLs when necessary according to the bonding system design. **Figure 4** shows an example of a link box with SVLs. In link boxes only the bonding leads are introduced, never the power cable itself.

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Figure 4: Example of a cross-bonding link box with SVLs and single-core bonding leads. Adapted from Cigré TB 797.

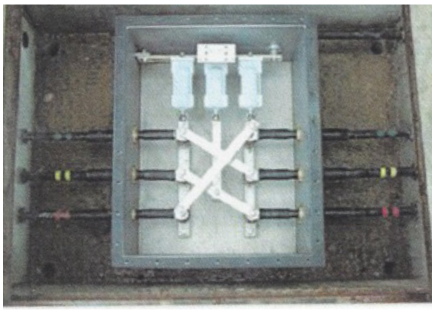

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Figure 2: Example of a single-point bonding system where bonding and grounding leads are identified. Adapted from Cigré TB 797.

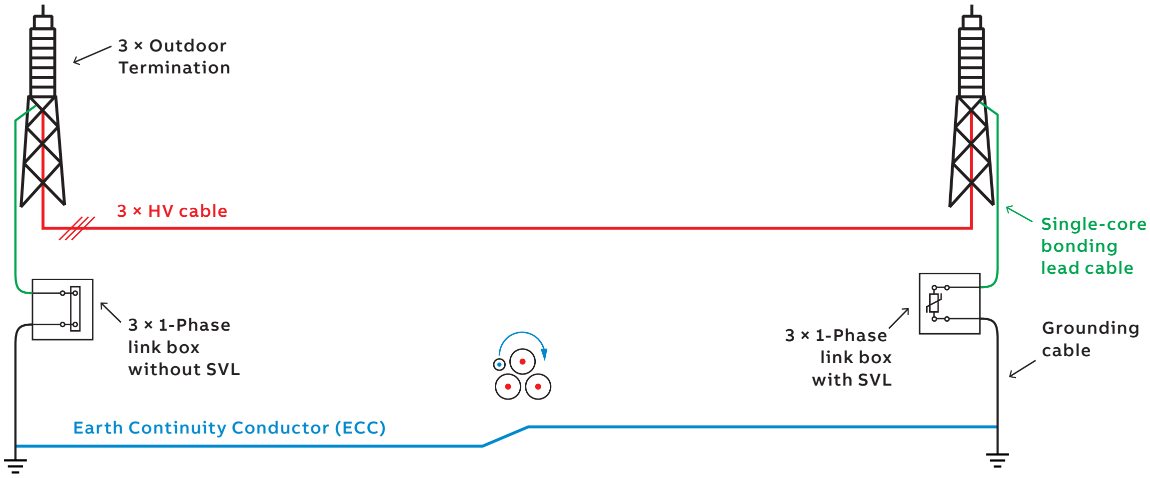

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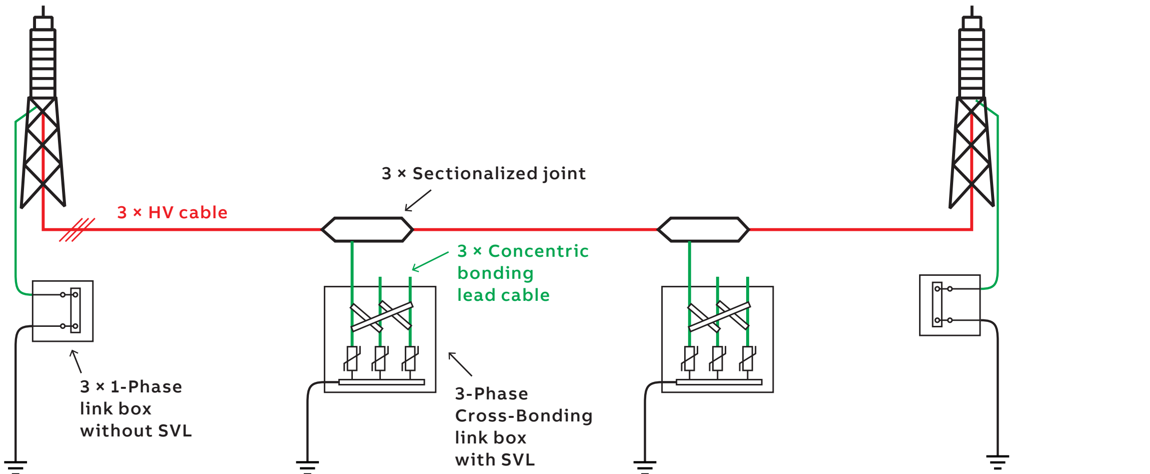
Figure 3: Example of a cross-bonding system where bonding and grounding leads are identified. Adapted from Cigré TB 797.



2.2 Solid-bonding
Metal sheaths are directly grounded at both ends (substation, tower) of the underground link (see **Figure 5**) and, sometimes, at defined intermediate points. In the case of a solid bonding, metal sheaths are considered at earth potential at every point of the link.

The solid bonding system uses bonding leads at both ends of a cable circuit. It is a simple and low-cost option, but the cable conductor current will induce circulating currents on the metal sheaths.

The induced currents produce Joule losses (which means an increase of the temperature), whose influences on cable circuit current rating can be significant. As a result, the cross-section of the cable conductor needs to be increased to maintain the circuit ratings due to the circulated current losses of the sheath. Because of the disadvantage of higher power losses in the cable system solid bonding is generally not used in HV and EHV systems.

Solid bonding is commonly used for low and medium-voltage systems, and for submarine cables where no other choice exists.

2.3 Single-point bonding
As already mentioned, if both ends of the sheath are earthed, the currents flowing in the sheath additional heat the cable during service. For thermal reasons it can therefore only be operated at a considerably reduced nominal current. Hence, it is of advantage to earth the cable sheath of a single-conductor cable only at one end, in which case the induction losses are zero, and only eddy current losses of about 1 % of the total losses remain in the sheath.

Therefore, for single-point bonding configurations only one end of the metal sheath is directly grounded to the earth link at the substation or tower. The other end of the metal sheath is open with an SVL typically connected between the open end and the local earth. The SVL is to protect the cable outer insulation (jacket) at the

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Figure 5:
Solid-bonding system (principle)

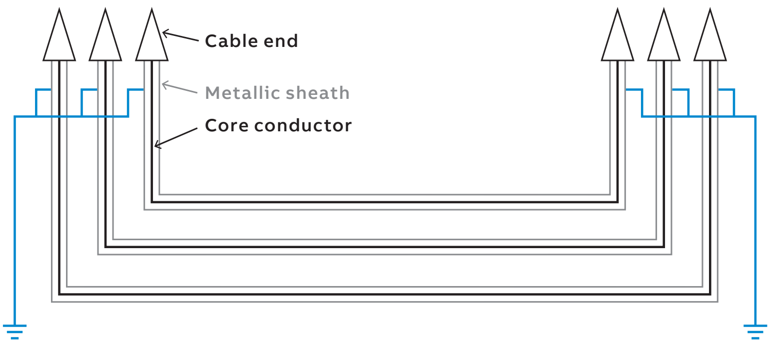

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Figure 6:
Single-point bonding system

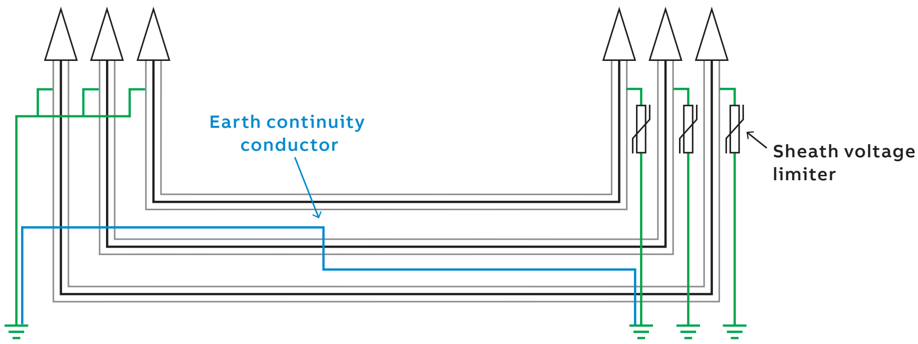

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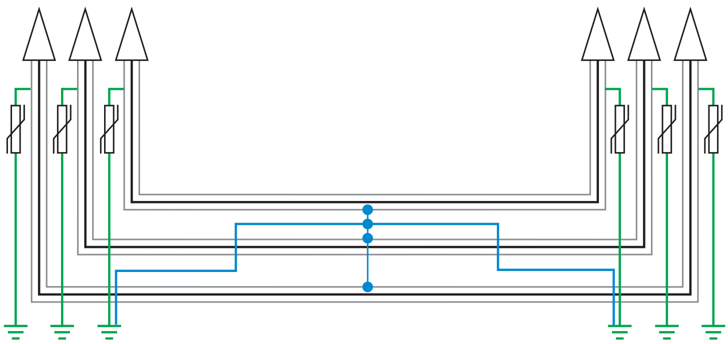
Figure 7:
Mid-point bonding system



open end from electromagnetic transients (lightning and switching overvoltages), see **Figure 6.** An earth continuity conductor (ECC) is installed in parallel with the power cable for single point bonded systems except when the cable terminals share the common earthing system. Single point bonding provides improved cable carrying capacity by eliminating the power losses in the cable sheath.

A special case of single-point bonding is the mid-point bonding, see **Figure 7.** A mid-point bonding system consists of two single-point bonding systems. Both ends of the metal sheath are open and the mid-point is grounded through the parallel earth continuity conductor. SVLs are typically connected between metal sheath and the local earth at the open ends. Mid-point bonding is used to reduce the induced voltage of the sheath to about the half of the single-point bonding of the entire cable length.

2.4 Cross-bonding
Figure 8 shows configurations of cross-bonding systems. In case of long cables, the sheath is interrupted at defined points by cross-bonding joints. Connections are made between the sheaths so that each sheath circuit connects the three phase conductors successively. In this way, induced voltages in the screen circuits are reduced (in the ideal case, three voltages offset by 120° are added up), and thus the sheath circulating currents are reduced.

In order to protect screen interruptions from overvoltages, SVLs are installed at cross bonding points, see **Figure 8a.** When cables are in single plane (flat) formation, the compensation of the induced voltages can be achieved if cables are transposed at cross- bonding points, see **Figure 8b.** It is worth mentioning that, even for a triangular laying, transposition of cables is recommended to limit induced voltages by nearby conductors.

2.5 Siphon lines (riser pole)
Circuits connecting overhead lines and underground cables (so-called siphon lines) require additional analysis in order to establish a safe and optimum cable sheath bonding system. At substations, the sheath can be grounded through a well-established earthing method. However, outside of substations, ideal grounding may not be always available. Due to exposure of the sheath when going from overhead line to the underground cable, high voltages on the sheath may be experienced during faults or lightning strikes.

In some countries the term riser pole is used to describe the place where a cable “rises up” on a tower to the overhead line.

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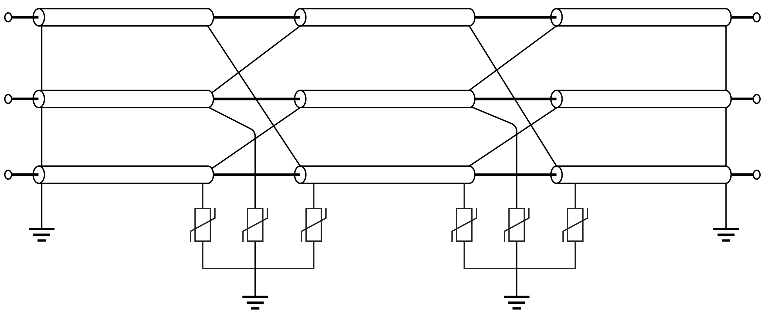
Figure 8: Typical cross-bonding systems



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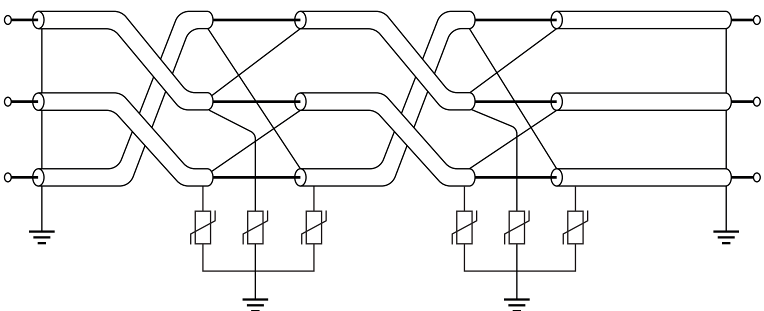
8a: a cross-bonding of long cables



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8b: cables transposed at cross-bonding points

3 Currents and voltages in cables and cable sheaths

It must be distinguished between the undisturbed service and short circuit conditions.
In undisturbed condition the voltage between the cable core and the earth and the load current is given by the system voltage U_S and the system design.

The nominal current flowing in the cable conductor induces a voltage in the cable sheath. If all three conductors of a three-phase cable are enclosed in a common sheath, the voltages induced by the tree phase currents in the sheath almost balance each other out. However, with single-core cables the induced voltages are considerable.

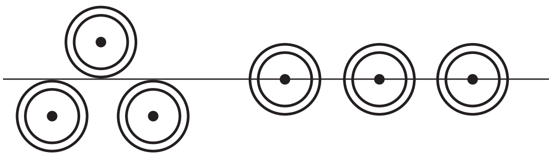

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Figure 9: Laying of cables in triangular (left) and single plain configuration (right)

For single-core cables two different methods of laying the cables are used, the triangular configuration and the single plain configuration, see **Figure 9.** The induced voltages depend on laying of the cables. The induced voltage U_i in the cable sheath must be calculated case to case considering the laying of the cable, the distance between the cables and the dimensions of the cables.

Two cases must be considered when estimating the power frequency voltages and currents in the cable sheath:

- the load current (steady state conditions), and
- the short circuit current with a limited time duration

The load current induces a voltage U_i in the cable sheath in the order of some tens to some hundreds of volts. As already mentioned, if the cable sheath is earthed at both ends of the cable, the voltage U_i drives a current through the cable sheath, which leads to additional power losses in the cable sheath and consequently to an increase of temperature in the cable. To avoid the additional power losses one end of the cables sheath is not connected to the earth, it remains “open”. In this case the insulation between the cable sheath and the earth is stressed with the induced voltage U_i, which can be neglected. In this case the current in the sheath is the eddy current only, which can be neglected as well.

The magnitude of the induced current is independent of the length of the cable, while the voltage induced on the metal sheath by the phase conductor current is proportional to the length of the cable.

In case a short circuit current is flowing in the cable the induced voltage U_i can reach some kilovolts. This voltage will stress the insulation for a short period of time, as long as the short circuit will flow. Typically, a short circuit current is switched of in less than 200 ms.

A simple calculation may give the order of magnitude of the induced voltages U_i in both the mentioned cases.

Assuming a max. possible induced voltage of U_i = 0.3 kV/(km and kA), a cable length of 1 km and a load current of 600 A (steady state conditions), we come to an induced voltage of 180 V.
If we assume a short circuit current of 20 kA and the same cable length, we reach a value of 6 kV for a limited time duration.

4 Overvoltages in cable systems

As consequences of overvoltages in cable sheaths, two aspects must be considered: insulation breakdown and ageing of the insulation.
It is well known that repeated overvoltage stresses negatively influence the ageing behavior of the cable insulation. This is true for the outer cable sheath insulation as well. Further, overvoltages may puncture the outer insulation (jacket), which will lead to ingress of humidity into the cable system.

4.1 Overvoltages due to lightning
When lightning strikes an overhead line in front of the transition pole, the surge is limited by the arrester that is universally mounted at this location and most of the surge current is diverted to earth. However, a surge voltage of significant magnitude can travel into the cable with a moderate level of current as well.

4.2 Overvoltages due to switching
Switching events in the transmission system, typically in substations, produce switching overvoltages, which may stress the bushing and cable insulation.

When there is a switching surge event on the phase conductor of a cable, the current through it will induce a voltage on the sheath in the same way it does at steady state or during fault events, even though the wave shape is significantly different.

4.3 Overvoltages due to earth failures and short circuits
In case of earth failures or short circuits in the system, outside the cable, temporary overvoltages with power frequency (TOV) will stress the insulation of the cable for a limited time duration. These overvoltages will not directly harm the insulation of the cable sheaths. Decisive is the current in the cable conductor, which induces the voltage U_i in the cable sheath.

If a short circuit between the cable conductor and the cable sheath or surrounding earth occurs in the cable itself, e. g. insulation breakdown due to mechanical damage, overvoltages will occur and high short circuit currents will flow. In such a case the cable is damaged completely, and most probably also electrical equipment connected to the cable, e. g. SVLs.

4.4 Overvoltages in cables and cable sheath
The magnitude of the overvoltages which occur between the cable conductor and the metallic sheath and between the metallic sheath and the surrounding earth can be calculated with the following estimations.

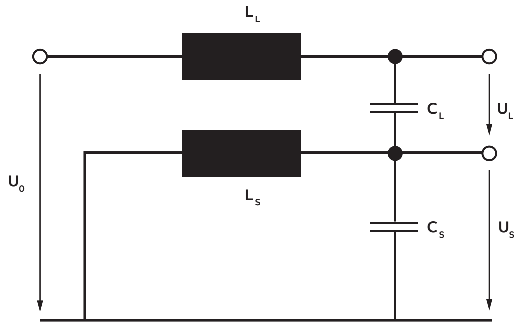
If the sheath is only earthed at one side according **Figure 10,** the voltage U_0 between the line conductor and the earth will be transferred to the voltage U_s and U_L at the remote end of the cable.

Without consideration of the load flow condition, the voltage depends on the capacitance C_S and C_E and the cable length. The capacities C_S (line to sheath) and C_E (sheath to earth) can be calculated according

$$C_{S,E} = \frac{2 \times \pi \times \varepsilon_0 \times \varepsilon_r}{L \times \ln (r_2/r_1)}$$

with
ε_0, ε_r dielectric constant
r_2, r_1 outer, inner radius
L cable length

— Figure 10: Capacitive voltage transfer



U_0: voltage between line and earth
U_L: voltage line-to-sheath
U_S: voltage sheath-to-earth

Therefore, the maximum voltage at the end of the cable can be estimated due to the capacitive voltage divider

$$U_{Smax} = \frac{C_S}{C_S + C_E} U_0$$

As mentioned, the voltage depends on the cable length. Therefore, the voltage U_{Smax} is only possible if the cable length is infinite. However, it is to be seen that the voltage between the sheath and the earth depends on the ratio of the capacitances C_E and C_S.

If we assume that C_E has the same value as C_S than the voltage stress on the outer insulation is half of the incoming overvoltage.

Example: In a 24 kV system a MO surge arrester of type MWK 23 is installed at the cable entrance.
In case of a lightning overvoltage the arrester may limit the voltage to the protection level of U_{pl} = 70.61 kV. In this case the lightning overvoltage at the sheath will reach up to 35.3 kV.

5 Protection of cable sheaths

5.1 General
Standard surge arresters at power system voltage levels are generally used at the cable terminals (e. g., substations or transition poles) to protect the primary insulation of the cable system. Sheath voltage limiters are used to protect the sheath bonding system insulation from transient overvoltage events due to lightning strikes and switching surges.

The application of a sheath voltage limiter is important. Without means to limit the transient overvoltages, the excessive voltage may cause an electrical breakdown of the sheath insulating jacket, sheath interrupts in sectionalizing points, bonding cables, the termination mounting insulation at the cable terminals, or other components as part of the sheath bonding system.
For example, the damage of the insulation jacket may make the metal sheath susceptible to corrosion and can result in unanticipated sheath circulating currents that may increase losses of the cable systems and cause hot spots along the cable rout.

Sheath voltage limiters must be applied to limit the overvoltage across the insulation to prevent insulation breakdown. It is required that the insulating jackets withstand the nominal a.c. voltage and impulse voltages. The magnitudes of power frequency overvoltages depend on rated system voltages, cable section length and the magnitude of cable fault currents.

The SVL is designed to withstand the power frequency voltage appearing during normal system conditions and during faults and to protect the bonding system insulation from transient overvoltages. The SVL is not designed to mitigate power frequency overvoltages (TOV) due to system faults (e. g. earth faults in the power system, or a short circuit in the cable itself).

A general practice of many countries is that the physical selection of the SVL is done by the cable material supplier in response to the user's specifications. Users specify the SVL requirements by providing fault current levels of the cable systems, the associated maximum induced voltages, and parameters for the transient overvoltage calculations and simulations. The supplier then selects the SVL and a link box enclosure. This is true for HV cable systems. For short cables or in MV systems the SVL is sometimes specified by the manufacturer of the SVL, based on information given by the client.

Connections between SVLs and the metal sheath of a power cable requires proper insulation coordination, considering the insulation withstand of bonding leads, metal sheaths, insulators, and the protective level of the SVLs. In general, it is desirable to keep bonding lead lengths as short as possible to provide proper protection against transient overvoltages. Bonding leads could be made of single-core cables or concentric cables. Bonding leads must be adequate to carry the expected short circuit currents and to withstand the expected overvoltages.

The jacket and sheath interrupts are generally the weakest insulation in a high-voltage power cable system. **Table 1** and **Table 2** show typical insulation withstand levels for sheath interrupts and jackets. As can be seen from the two tables, the withstand values for the jacket is related to the lightning impulse withstand voltage (LIWV) of the main insulation of the cables.

5.2 Selection of SVLs for cable sheaths protection
The voltages and currents of the cable sheaths are influenced by:

- The currents in the cable (load current or short circuit current)
- The length of the cable
- The laying of the cables, single or three phases (triangular or single plain, spacing between cables)

The induced voltage in the cable sheath due to the load current can be neglected, while the induced voltage due to the short circuit current is decisive for the selection of the SVL.

Considering the TOV curve of the arrester the induced voltage, which is applied to the arrester for the time until the fault is cleared, needs to remain below the curve with "no prior energy".
It is assumed, that SVLs are not prone to nearby lightning events which is obviously the case in tunnel systems and with buried cables.

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Table 1: Impulse type test voltages as specified by IEC 60229 for cable sheath insulating jacket.

Highest voltage for equipment U_m	LIWV of main insulation	Impulse test level (1.2/50 µs) of jacket
52 and 72.5 kV	250 to 325 kV	30 kV
123 kV to 170 kV	550 to 750 kV	37.5 kV
245 kV to 420 kV	1050 kV	47.5 kV
362 kV to 550 kV	1175 to 1425 kV	62.5 kV
550 kV	1550 kV	72.5 kV

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Table 2: Additional requirements according French Standard NF C 33-254

Highest voltage for equipment U_m	LIWV of main insulation	Impulse test level 1.2/50 µs of jacket	AC withstand level of jacket
72.5 kV	325 kV	50 kV	20 kV
100 kV	450 kV	50 kV	20 kV
245 kV	1050 kV	50 kV	20 kV
420 kV	1425 kV	62.5 kV	20 kV

With an approximation the continuous operating voltage U_c for SVLs can be calculated as follows:

$$U_c \geq \frac{U_i \times I_K \times L_K}{T}$$

where

- U_c continuous operating voltage of the surge arrester in kV
- I_K maximum short circuit current of the cable (single phase) in kA
- L_K length of the unearthed cable section in km
- U_i the voltage induced in the per unit length of the cable sheath in kV/(kA × km)
- T TOV factor

5.2.1 Example of cable sheath protection in distribution systems

As an example, for the selection of an SVL in a distribution cable system we may consider a cable length of 900 m and a short circuit current of 16 kA (single phase). We assume for the induced voltage a worst-case value of $U_i = 0.3$ kV/(km×kA) and again as worst case in a distribution system a fault time of $t = 3$ s. We choose a MO surge arrester of type MWD with a TOV factor of $T = 1.412$ (without prior energy).

With the above given equation, we come to

$$U_c \geq \frac{0.3\text{ kV} \times 16\text{ kA} \times 0.9\text{ km}}{(\text{km}\times\text{kA})\ 1.412} = 3.059\text{ kV}$$

We choose the next higher U_c value from the data sheet and come to an MWD 04 for this application, assuming the installation is not outdoor.

It was assumed that the cable itself is protected with a MO surge arrester of type MWK 23, which is typical for a cable system with a system voltage of $U_s = 24$ kV. For the selection of the MO surge arrester for protecting the cable against overvoltages see APPLICATION NOTE 3.0.

It is advisable to select for the SVL the same ratings as for the MO surge arrester for the cable protection. In the example given both, the SVL and the MO surge arrester are of class SL with $I_n = 10$ kA, repetitive charge transfer rating of $Q_{rs} = 1.6$ C and rated thermal energy $W_{th} = 6.25$ kJ/kVUc.

With a residual voltage of $U_p = 12.3$ kV at I_n the MWD 04 provides very good protection, assuming that the jacket was tested to withstand 30 kV impulse voltage.

The protection level of the SVL should be as low as possible because the withstand strength of the sheath insulation (jacket) during its service life may age.

5.2.2 Examples of cable sheath protection of a HV cable

For transmission cable systems detailed calculations must be performed.

The following examples of two HV cable systems, the 380 kV VPE cable system in Berlin/Germany and the 420 kV cable system for NGC-London/UK show as result of the investigations the selected SVLs.

- 380 kV VPE cable system Berlin: POLIM-H 09 N.
- 420 kV cable system for NGC-London: POLIM-H 12 N.

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Figure 11: Possible connections of MO surge arresters and SVLs

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Figure 11a

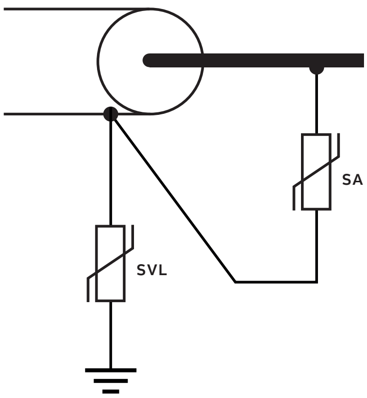

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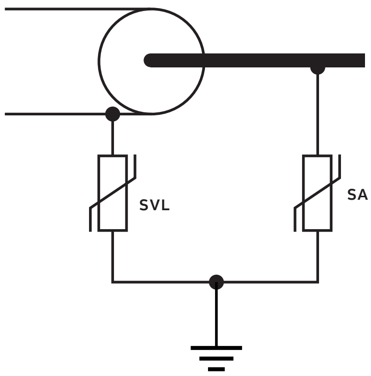
Figure 11b



SA: MO surge arrester
SVL: sheath voltage limiter

Both HV cable systems are placed in tunnels. The installed SVLs are equipped with a sophisticated disconnecting mechanism to avoid problems with failed SVLs in the tunnel system. It also provides information about the status of the SVLs (connected or not connected).

5.3 Connection of MO surge arrester and SVL
As mentioned, surge arresters for the protection of cables should be placed as close as possible to the cable bushing. If on one side of the cable a surge arrester for cable protection is installed, and an SVL for the protection of the cable sheath, two possibilities arrangements exist, see **Figure 11.** Arrangement a is to be preferred, because it provides best (lowest) protection level for the cable insulation.

The principle rules are the same for both possibilities:

- The MO arrester and the SVL should be placed as close as possible to the cable bushing. The cable sheath should be connected on the shortest way with the foot point of the MO arrester.
- The MO arrester should be installed in the way of the overhead line, as indicated in **Figure 12.**
- It is advisable that the MO surge arrester and the SVL are of the same rating.
- The resistance of the earth connection should be as low as possible.

5.4 Grounding
Typical values of the resistance are 0.1 to 1 Ω in a substation, 8 to 10 Ω on a transition tower between an underground cable and an overhead line, 10 to 20 Ω on a regular tower, and 5 to 10 Ω at a joint pit.

6 Special protection on GIS cable terminations against high frequency transient overvoltages.

High frequency transient enclosure voltage (TEV) is caused by lightning surges, operations of lightning arresters, phase-to-earth fault currents, or switching surge discharges between contacts. The high frequency transient currents cause localized transient overvoltages because of the relatively high reactance of earth connections. The GIS enclosures are designed to withstand such electrical stresses. At discontinuities as in the case of the connection of GIS and a HV cable termination sheath sectionalizing insulators are between the GIS and the cable sheath.

Two main options are used to protect the system from the high frequency transient overvoltages at the discontinuities between the GIS enclosure and cable terminations.

1. Install a metallic earth connection between the GIS enclosure flange and cable sheath, see **Figure 13.** This connection has the advantage of avoiding overvoltage between the GIS enclosure and the cable sheath. The disadvantage is that it causes permanent circulation of current in a closed loop formed by the multiple connections to ground.
2. Install bypass SVLs across the sheath sectionalizing insulator to limit the overvoltage under transient conditions between the components electrically connected to the GIS enclosure and the cable sheath. The SVLs need to be mounted close to the gap to be protected and connected by short leads of low impedance.

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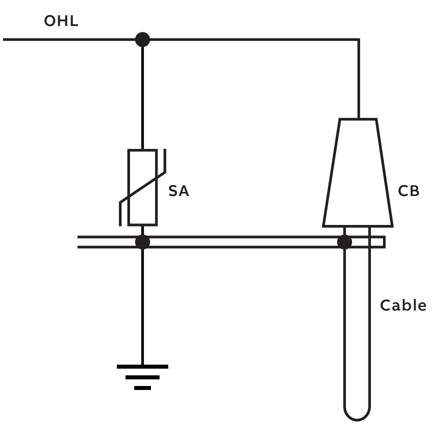
Figure 12: Arrangement of MO surge arrester and cable bushing



OHL: overhead line
SA: MO surge arrester
CB: cable bushing

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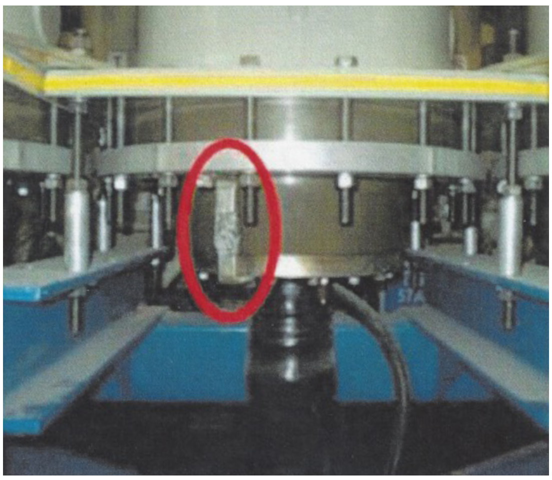
Figure 13: Example of earth connection between GIS enclosure and cable sheath



In the case of single-point bonding connection where there are sheath voltage limiters (SVLs) installed on the GIS side, the sheath temporary overvoltage that appears between cable sheath and earth when a phase-to-ground fault occurs in the power grid is seen by both limiters: the sheath voltage limiter which protects the cable sheath, and the bypass sheath voltage limiter located between the cable sheath and the GIS enclosure, see **Figure 14.** Therefore, the bypass SVL's rated voltage should be equal or higher than the sheath voltage limiter's rated voltage, in order to ensure the integrity of the bypass SVLs in case of phase-to-ground fault.

7 Economical considerations

Cable sheaths of power cables in distribution networks are generally earthed at both cable ends. This method avoids any dielectric stress on the sheath insulation due to transient overvoltages. The disadvantage are additional power losses in the distribution system. The power losses depend on the type of cable, the load current and the method of the cable laying. For typical medium voltage polymeric insulated cables, the additional power losses can be up to 10% of the total power losses in the cable system. Besides the technical disadvantage of increased temperature in the cable the economic aspect should be considered as well.

In the deregulated market the expense of erection and maintenance of capital assets becomes more and more interesting. This applies to the cost of loss of a MV cables with long service time of more than 30 years as well. The additional power loss in the cable sheaths is an unnecessary part of the total costs for power loss.

To avoid the additional losses the cable sheaths are earthed on one side only, and the other open side needs then to be protected by SVLs. Therefore, the cost of a set of SVLs must be compared with the cost of the additional power losses.

The cost-benefit relation between arresters and the additional power losses of the cables is a reason for choosing arresters, particularly for cable sections of more than 500 m and load currents of more than 30% of the rated current. The benefit is especially given for cable systems of 24 kV and 36 kV.

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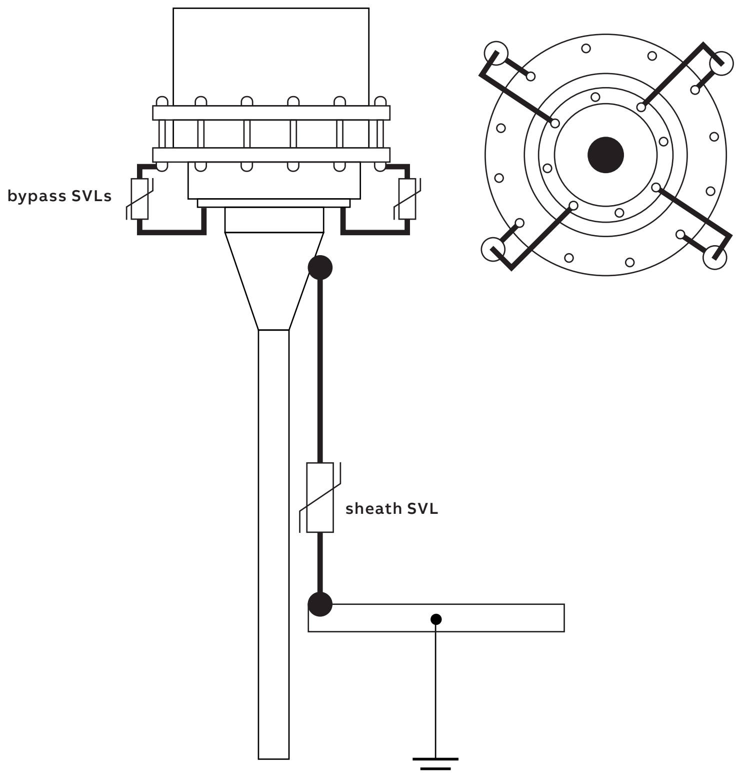
Figure 14: Single-point bonding connection with sheath voltage limiters installed on the GIS side



Summary

Cable sheath protection is a special field of the cable protection in general.

A sheath voltage limiter (SVL) is basically a MO surge arrester under a different terminology. Sheath insulation is necessary to electrical isolate the cable metal sheath from earth and to prevent metal sheath corrosion. The sheath insulation is subjected to voltages induced by the power frequency cable conductor current and fault current, and by the transient voltages imposed to the cable conductor by lightning or switching surges.

The cable sheath is earthed on one side only to avoid additional power losses in the cable sheath. At the open end an SVL is installed to protect the cable sheath against overvoltages.

Depending on the system voltage different bonding principles have been developed. The cable sheaths are bonded and earthed in such a way to eliminate or reduce the induced currents in the sheaths.

Sheath voltage limiters must be applied to limit the overvoltage to prevent insulation breakdown. Further, SVLs have a positive influence on the aging of the insulation by reducing the magnitude and steepness of overvoltages.

Cable terminations of gas-insulated substations (GIS) may need SVLs as well.

Besides the technical aspects of the application of SVLs economic aspects must be considered. In medium-voltage cable systems the reduction of power losses in the cable sheaths reduce the total costs of power losses.

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