Paper ID – 10670 Session 2022
B2 – OVERHEAD LINES

PS2 LATEST TECHNIQUES IN ASSET MANAGEMENT, CAPACITY ENHANCEMENT, REFURBISHMENT.

Upgrading the transmission capacity of existing high-voltage lines using insulated suspension chain ISC

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SUMMARY

In order to meet the growing demands of the energy future and developments in society and the economy, Axpo is making sustained investments in network expansion. The demands on tomorrow's electricity supply require the optimum use of existing electricity transmission systems. The construction of new high-voltage overhead lines requires complex and lengthy approval procedures and planning work. With the upgrading of existing high-voltage lines, the voltage will be increased e.g. from 50 kV to 110 kV or from 220 kV to 380 kV while retaining the existing mast geometry. This will make the electricity systems more efficient and reduce losses by 75 percent. Therefore, an optimal use of existing high-voltage overhead lines is purposeful.
This article describes how an existing high-voltage overhead line can be upgraded by an ISC (Insulated Suspension Chain) for a transmission voltage U that is about twice as high. The existing pylons of the overhead line are used unchanged, so that complex approval procedures can be reduced in scope.

KEYWORDS

Transmission power - Upgrading - Insulated suspension chain

1 STATE OF ART

Where, for economic, ecological or legal reasons, the expansion of the high-voltage grid cannot be achieved with conventional solutions in the time desired by the operator, solutions using HTLS (High Temperature Low Sag) have been proposed in the literature.

One proposed solution [1] is the use of ACCR (Aluminium Conductor Composite Reinforced) conductors, which allow operating temperatures of up to 210 °C compared to conventional ACSR (Aluminium Conductor Steel Reinforced) conductors. According to the specifications in [1], the use of ACCR conductors with the same cross section allows a doubling of the transmission capacity with the same sag as with ACSR conductor at 85 °C. However, this solution requires the complete replacement of the conductors, which is associated with considerable expenses for higher losses at high temperatures, approval procedures and installation.

Another proposed solution [2] is the DTLR (Dynamic Thermal Line Rating). A short-term overload of existing overhead lines is predicted on the basis of meteorological parameters like wind speed, wind direction, ambient temperature, solar radiation, etc. The variation of weather conditions along the line and with time is of great importance for thermal behavior of the conductor. Modelling the variation of the conductor temperature along the conductor and radially within the conductor is therefore recommended. The DTLR method is currently mainly used in the 400 kV levels and above.

From Axpo's point of view, a permanently effective increase in transmission power is preferred. After comparing the existing possible solutions [1,2], the aim was to increase the operating voltage of the existing overhead line network with an operating voltage of 50 kV to 110 kV and 220 kV to 380 kV using (Insulated Suspension Chain) ISC. As an example, Fig. 1 shows a typical 50 kV high voltage transmission line installed in Switzerland.

Fig. 1 View of a 50 kV high-voltage line

2 *Legal requirements*

It is very difficult in the current situation to find new routes for a high-voltage overhead line and to obtain a building and an operating permit for it. Even the modification of an existing overhead line requires an extensive and time-consuming planning and approval procedure. It is therefore proposed to re-insulate an existing overhead line by means of an ISC, while maintaining the same suspension point, the same ground clearance and without the supports.

3 *Technical requirements*

For the upgrade of an overhead line in Switzerland, the withstand voltages and legally required minimum clearances are specified in Table 1. The IEC values are shown in*Table 2* Table 2 for comparison. The clearances required in EN 50341-1 are shown in Table 3. In addition, there are the mechanical requirements for tensile loads, sag and deflection because of wind and ice loads. Also the pollution site severity has to be considered. Increased legal requirements for bird protection require their consideration in an upgrade.

Table 1 Required withstand voltages and clearances of the line regulation, Source: LEV Verordnung über elektrische Leitungen

		Rated voltage			
		45 kV	**110 kV**	**220 kV**	**420 kV**
BIL (+/-)	kV	250 … 290	450 … 550	950…1175	1300..1675
AC (1 min) AC + Rain (1 min)	kV	95 … 110	185 … 230	395…530	570…720
SIL (+/-)	kV	NA	NA	NA	1050
		Clearances			
Phase – Ground Phase – Phase	m	0.52	0.92 …1.12	1,93…2,14	2,64…2,90

Table 2 Required withstand voltages and clearances in IEC 60071-1:2019

		Rated voltage			
		52 kV	**123 kV**	**245 kV**	**420 kV**
BIL (+/-)	kV	250	550	850…1050	1050…1425
AC (1 min)	kV	95	230	360…460	NA
SIL (+/-) Phase to earth	kV	NA	NA	NA	850…1050
		Clearances			
Rod-structure	m	0.48	1,1	1,7…2,1	2,1…2,85
Conductor-structure	m	NA	NA	1,6…1,9	1,9…2,6

Table 3 Required clearances in EN 50341-1:2012 [1)]

		Clearances			
		52 kV	**123 kV**	**245 kV**	**420 kV**
Phase - Ground	m	0.6	1	1,7	2,8
Phase - Phase	m	0,7	1,15	2	3,2

1) Rated voltages are not specified in EN 50341-1:2012

4 *Engineering process*

An ISC was selected as the solution to the problem. This allows the existing geometry of the support to be retained. For installation, the existing conductor is cut and reconnected to the ISC by a connection fitting. In doing so, the tension of the conductor and the wind deflection must be taken into account. The choice of conventional insulators is made according to the degree of pollution. The high voltage cable used in an ISC is a conventional high voltage cable made of cross-linked polyethylene (XLPE) without outer conductive layer and without the usual shield. In addition, a silicone heat shrinkable sheath is applied to protect the cable insulation (XLPE) from environmental influences. Further sheath silicone shields are applied to the silicone sheath for better drainage of rainwater. The electrical field of the entire ISC was optimised by a numerical field calculation. In normal operation the field strength should remain far below the inception field strength of 25 kV/cm. The insulation coordination for an ISC is not specified in the standard IEC 60071-1 [4]. Therefore, a customised solution was used. The altitude correction is performed according to IEC 6007-2 [5].

4.1 Insulated suspension chain

The upgrade of an existing overhead line to a higher voltage is not feasible for many line support geometries while maintaining the distances according to Table 1. Fig. 2 shows the principal arrangement of a 50 kV concrete pole with 50 kV conventional insulators and ISC for 110 kV without changing the pole geometry. Critical here is the distance between the conductor and the crossarm directly below. As a technical solution, the arrangement of three insulators is proposed here, which carries the conductor on both sides and an ISC below the insulators as shown in Fig. 3. The cross section of the cable of the ISC is shown in Fig. 4. The pole top geometry remains unchanged. In this way, existing 50 kV overhead lines can be reinsulated to 110 kV. This permanently more than doubles their transmission capacity from 65 MVA to 142 MVA. The basic principle of the Axpo patented ISC [3] can also be transferred to other voltage levels, e.g. 110/220 kV or 220/380 kV with the same principal design, shown in Fig. 7.

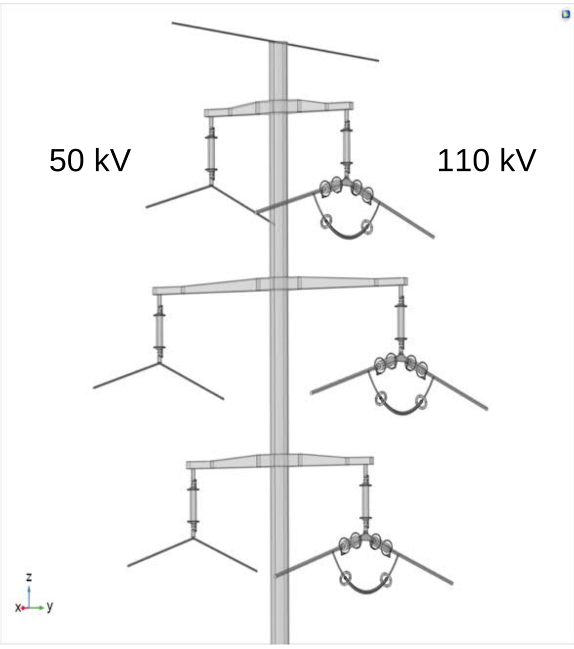


Fig. 2 Principal arrangement of conventional insulators and ISC on a 50 kV high voltage pole and upgraded 110 kV system

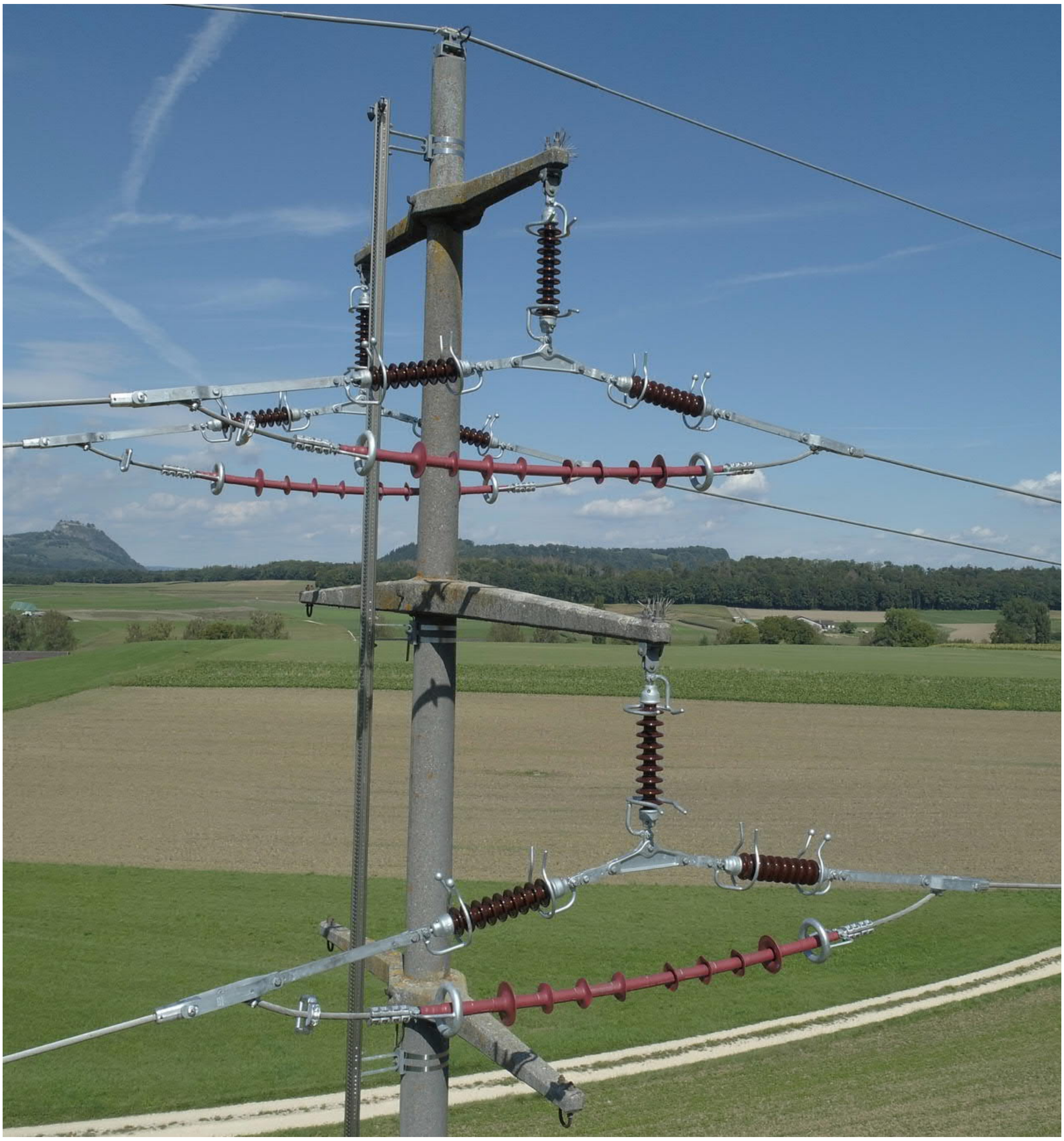


Fig. 3 Pilot installation of an upgraded 50 kV high-voltage line to 110 kV in the Axpo network

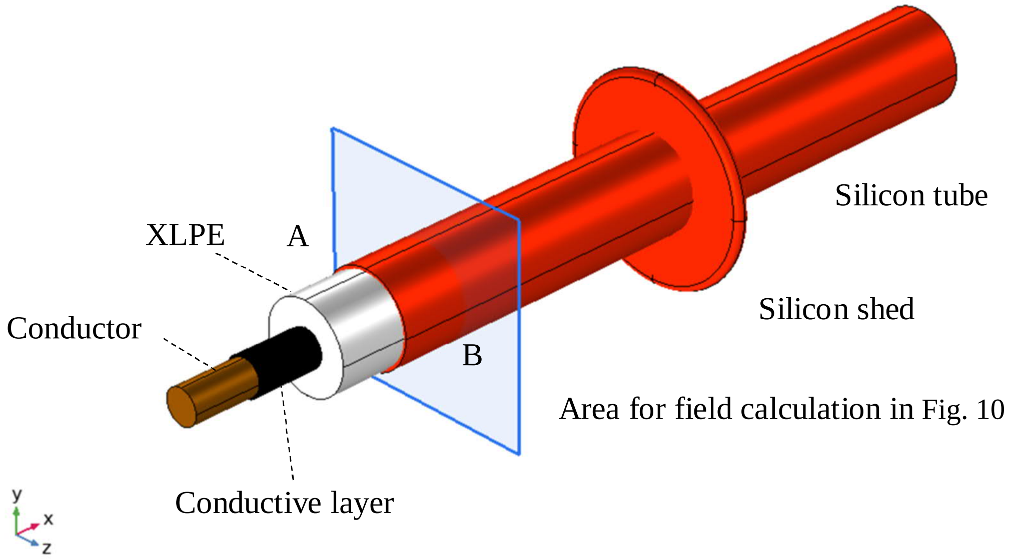


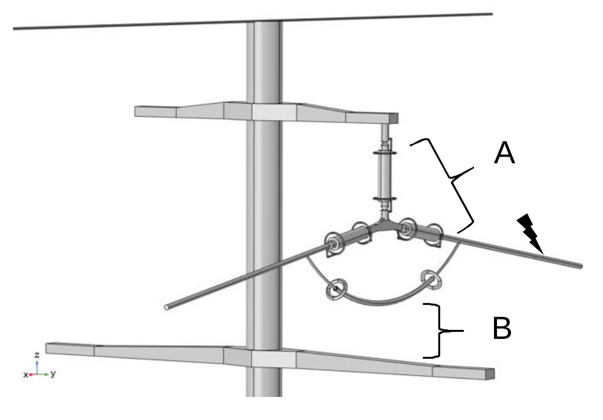
Fig. 4 View of the cable

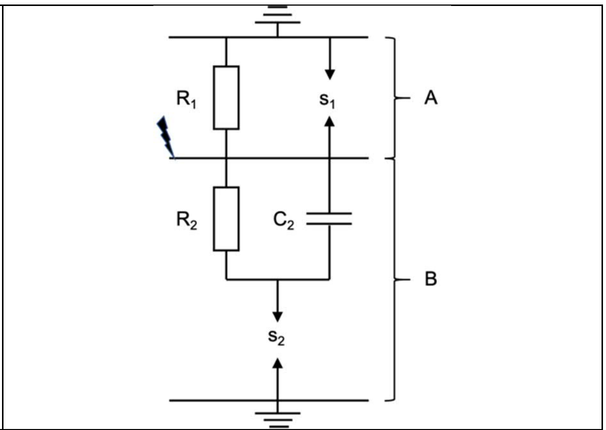
4.2 Numerical field calculation

An ISC according to Fig. 3 is a complex insulation system. It consists of three conventional insulators and a special cable section. The conventional insulators are arc-protected against possible damage caused by flashover due to pollution and lightning surges. The electric field along the cable section is essentially radially directed. In the area above the crossarm, the highest electric field strength prevails at the outer surface of the cable where it consists of a small section of insulating material (XLPE) covered with a silicone heat shrinkable sheath and the remaining clearance to the mast cantilever. At the ends of the cable section corona shields are attached to control the field strength.

This is a three-dimensional arrangement whose field strength values are to be determined at the relevant critical points. To limit the calculation time, the space for the calculation is reduced according to Fig. 5. The field plot is shown in Fig. 6. As expected, the highest field strength is found at the surface of the arc protection fittings of conventional insulators and at the corona shields. Fig. 8 shows the lines of equal field strength in the area between corona shield and the surface of the cable. The corresponding components of the field strength on the surface of the silicone layer are shown in Fig. 9. The values are within acceptable limits, still the inception field of surface discharge (z-component) is roughly an order lower than the limit of breakdown (radial component). ~~Only a small z-component exists. The magnitude is below 25 kV/cm at an operating voltage 89 kV peak.~~ When exposed to a lightning impulse voltage of 550 kV the values are also below 25 kV/cm.

The field strength inside the cable on a line AB, see Fig. 4, is shown in Fig. 10. Inside of the XLPE insulation material the field strength is not critical. On the surface of the silicone layer the field strength at operating voltage is below 25 kV/cm. Higher values occur when exposed to lightning impulse voltage. However, the field strength acts on the surface of the insulating material XLPE and not on a metallic surface. Therefore, a streamer development is not to be expected. The field calculation has therefore confirmed the design values and the performance was verified in a type test.





Arrangement for field calculation	Equivalent circuit for insulation coordination

S_1 effective clearance between corona shields
S_2 clearance between mast cantilever and surface of silicon tube

Fig. 5 View of the arrangement used for field calculation and insulation coordination

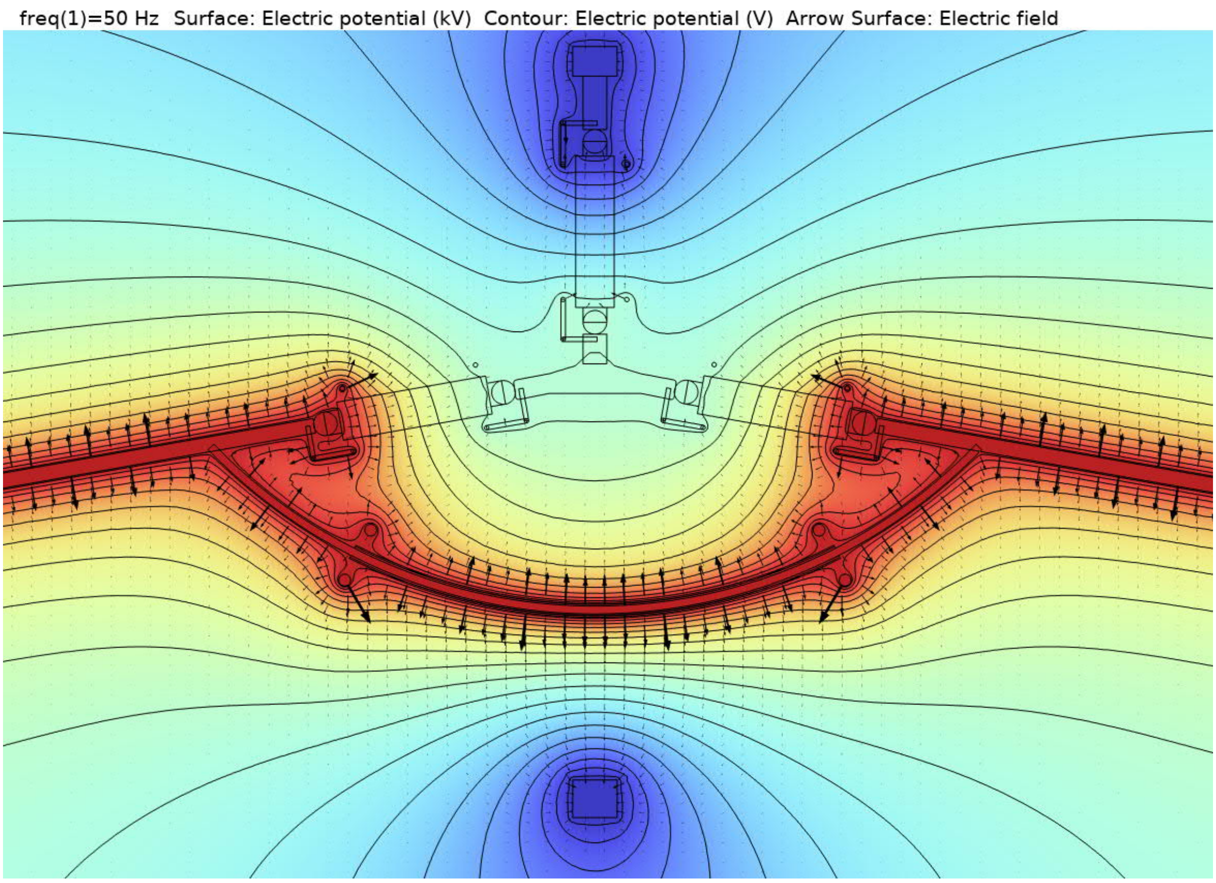


Fig. 6 Field plot of the ISC for 110 kV, calculated for rated voltage. Shown is a cross sectional view through the ISC. View with arrows of electric field strength in proportional scaling.

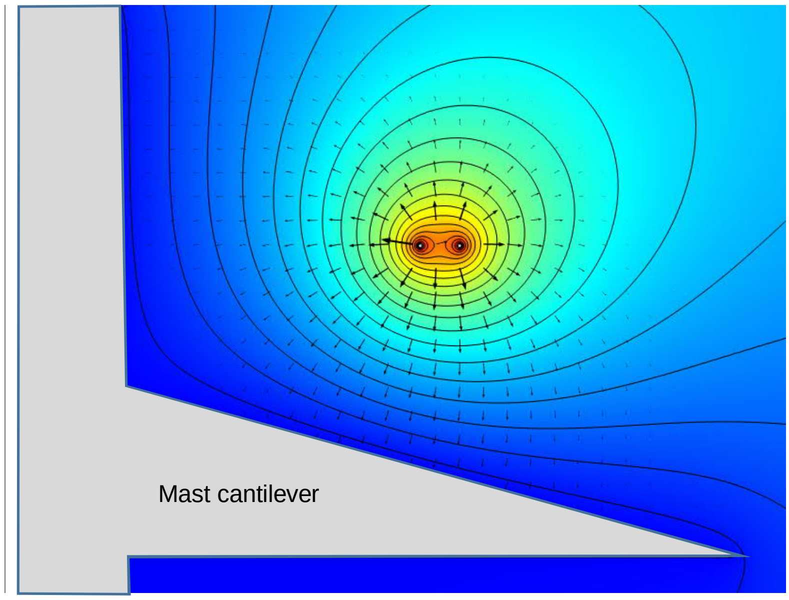
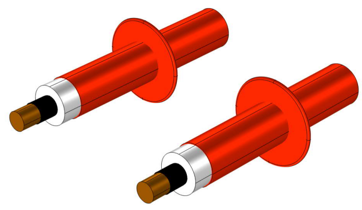
	
Field plot with equipotential lines and surfaces	ISC-bundle conductor. For key refer to Fig 4

Fig. 7 2-D-Field plot of the ISC for 420 kV, calculated for rated voltage. Shown is a cross sectional view of a ISC-bundle conductor above a mast cantilever. View with arrows of electric field strength in logarithmic scaling.

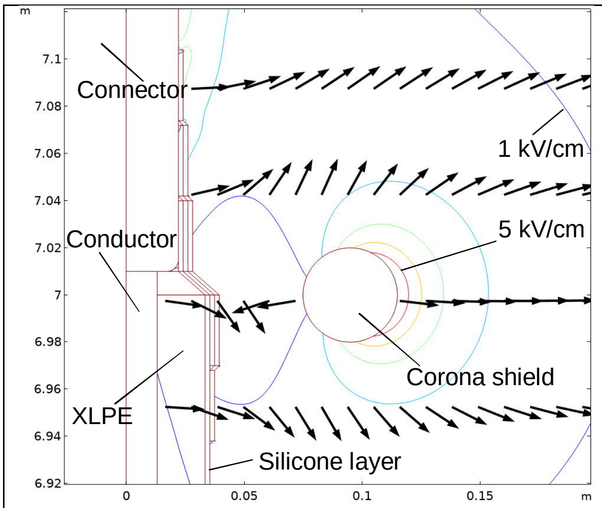
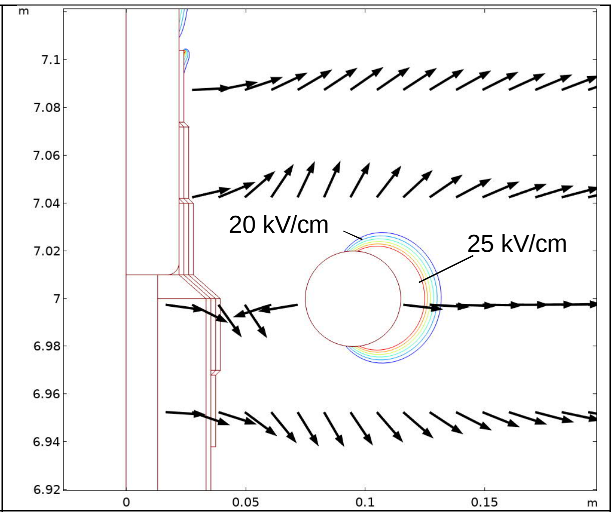
	
AC 89 kV peak. Range 1 to 5 kV/cm	550 kV BIL. Range 20 to 25 kV/cm

Fig. 8 Field plot with lines of equi-field strength and arrows of the electric field of an ISC for 110 kV, calculated for operating peak voltage and for BIL.

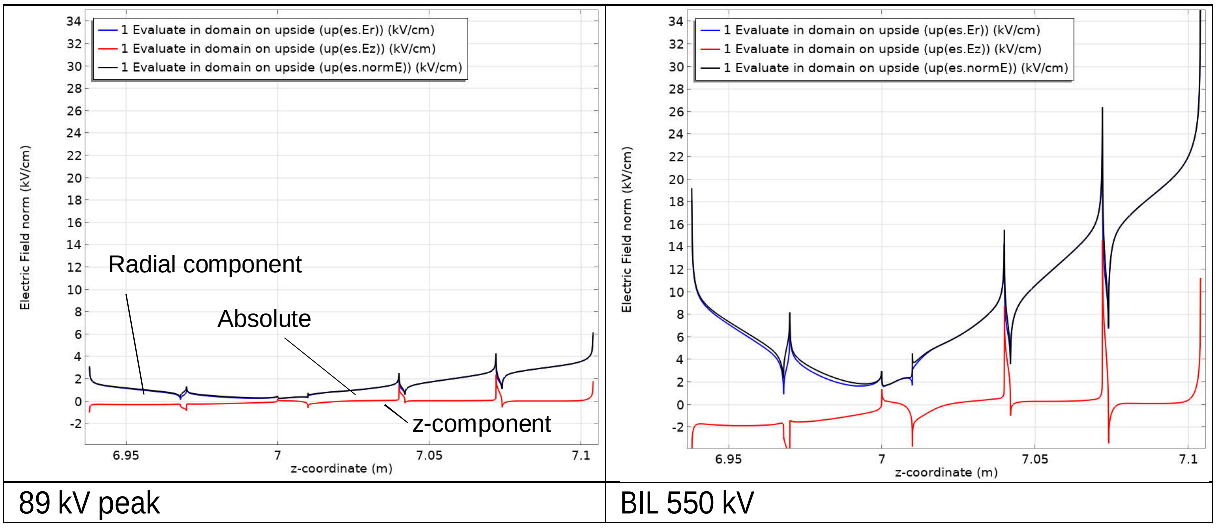


Fig. 9 Field plot with electric field strength along vertical direction of the surface of the silicone heat shrinkable tube for 110 kV, calculated for rated peak voltage and for BIL.

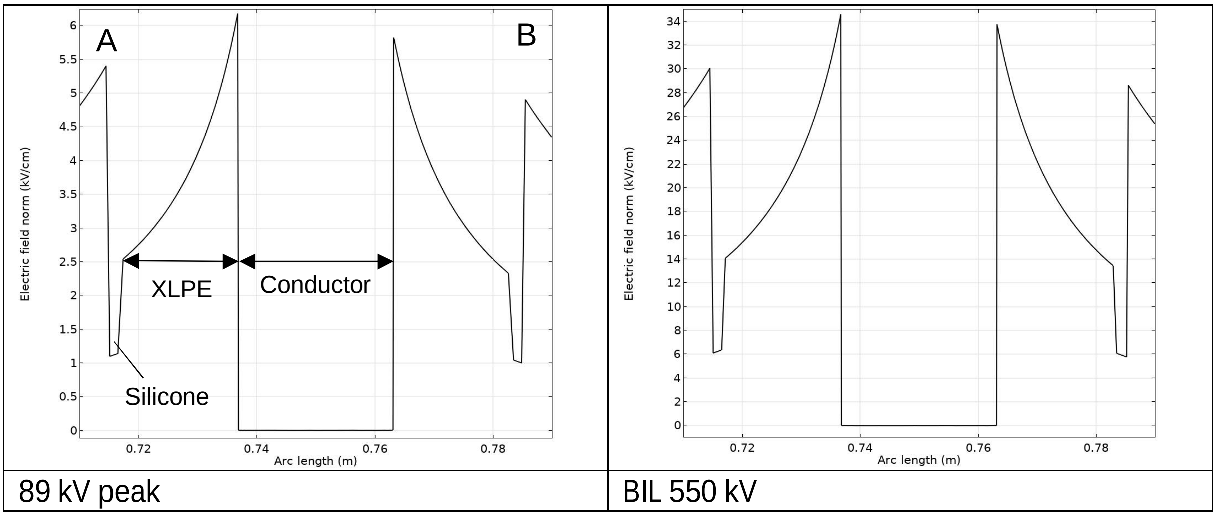


Fig. 10 Field plot with electric field strength on a vertical line (Line AB in Fig. 4) through the cable of of an ISC for 110 kV, calculated for rated peak voltage and for BIL.

4.3 Insulation coordination

The aim of insulation coordination is to prevent flashovers along the surface of the silicone surface. Flashovers due to lightning surges should always lead to flashover of the conventional insulators. The insulation coordination procedure according to IEC 60071-1 cannot be used for an ISG as the conductor is insulated. Therefore, an adapted method was developed and verified in the laboratory. In Fig. 5, area A is represented by solid insulating material of the insulators and the air insulated corona rings connected in parallel, forming the airgap s1. Area B is characterised by a series connection of the solid insulating material (XLPE) of the cable and an air gap s_2. Parallel to the XLPE, the interface of the silicone heat shrinkable tubing to the surrounding air must also be taken into account. The electrical equivalent circuit diagram of these two areas is shown in Fig. 5. Area A falls within the application of the rules for insulation coordination according to [4]. Area B is not provided for in the rules of insulation coordination [4] and requires special attention. In the equivalent circuit diagram in Fig. 5 the area B is represented by the capacitance C_2 of the cable with silicone heat shrinkable tube and the surface resistance R_2 of the silicone heat shrinkable tube and the air gap s_2. The insulation coordination is considered as follows: For normal operation the average field strength should remain below the limit of 5 kV/cm which is the limit for the average field for positive streamers. The maximum field strength at the edge of the silicone heat shrinkable tubing should remain below the streamer inception field strength of 25 kV/cm. However, these values apply to the discharge between metal electrodes. Values from the numerical field calculation for a 110 kV ISC are shown in Table 4. It should be noted that the insulation distance B consists of the capacitance C_2 and the parallel resistor R_2 and the air gap s_2. When the silicone layer is dry, there is only a capacitive (insulated) coupling to the live conductor. In wet or heavily polluted condition, a certain ohmic coupling exists via the silicone layer. Therefore, the above values should only be used as a design guide. A calculation of the flashover voltage of the insulation system B is not possible. The values assumed in the insulation coordination were therefore confirmed by a type test. An essential aspect is the coordination of the insulation systems A and B in Fig. 5 for lightning surges. In order to protect the silicon insulation of the cable, it should be achieved that in the case of high lightning surges only flashovers occur between the arcing protection fittings in area A. This objective was achieved during the coordination-type test through optimisation of the distances between the arcing protection fittings until no flashover occurred in section B.

Table 4 Values of field strength for a 110 kV ISC. Values are peak values.

		Service	**Type test**	
			AC	LI
Average field strength between silicone heat shrinkable tube and crossarm **E_m**	kV/cm	1,5	4,35	7,5
Maximum field strength on Silicone heat shrinkable tube **E_{max}**	kV/cm	5,3	15,3	26,5

5 *Type test and pilot installation*

In a type test, the required test voltages according to Table 1 were successfully verified. The insulation-coordination test was carried out and the optimum position of the corona shields was determined. In the Axpo AG network, a 50 kV high-voltage line was upgraded to 110 kV and is operating successfully since September 2020, see Figure 3.

6 *Bird protection test*

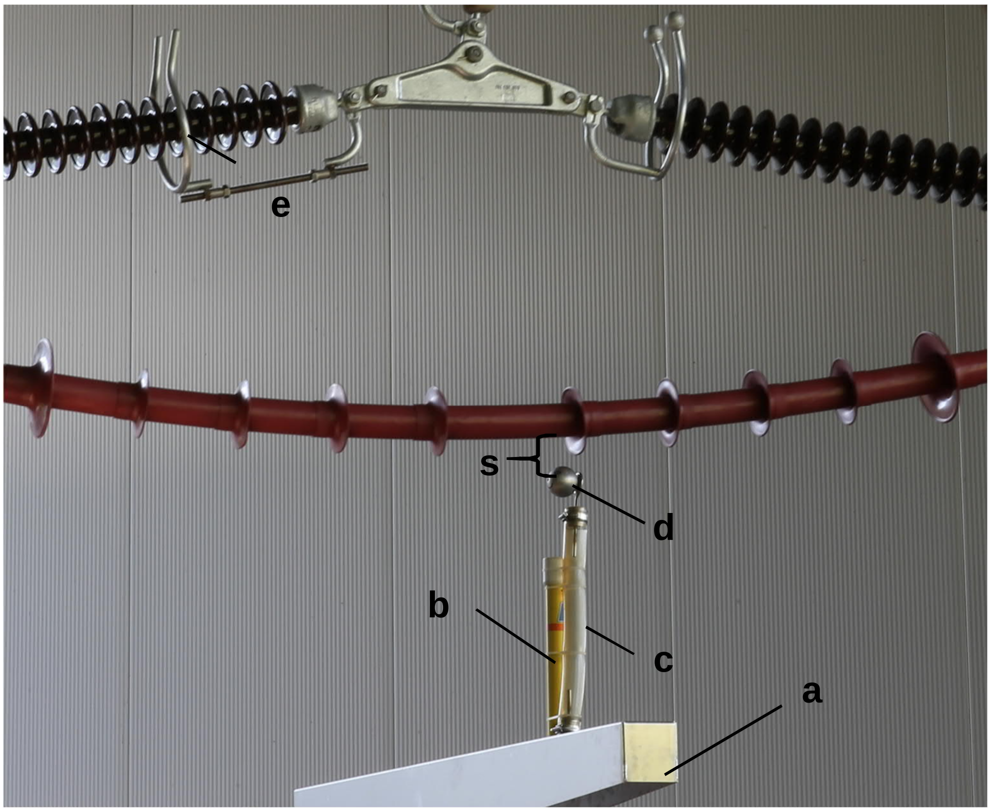
With state of the art of overhead power lines, birds can touch the line and die when approaching or flying off a crossarm. With an ISC, on the other hand, there is no danger to birds. To prove this thesis, a bird was replaced by a dummy consisting of a resistor of 4.9 kOhm [7] with an attached sphere of 5 cm diameter according to Fig. 11 A and placed below the ISC. The test was carried out with a nominal voltage of 123 kV corresponding to 71 kV line to ground. The current in the dummy bird was measured. The specific energy and the charge were evaluated from the registered current oscillograms and are shown in Table 4. From the experiments with an electrical image of a large bird placed between the ISC and a crossarm below, the following conclusions can be drawn:

Up to the highest operating voltage of 123 kV (71 kV line to ground), no flashover against ground and no discharge on the surface of the ISC occurred. This also applies to the case when the resistance model of the bird bridges the ISC with the crossarm (s = 0 in Fig. 11 B).

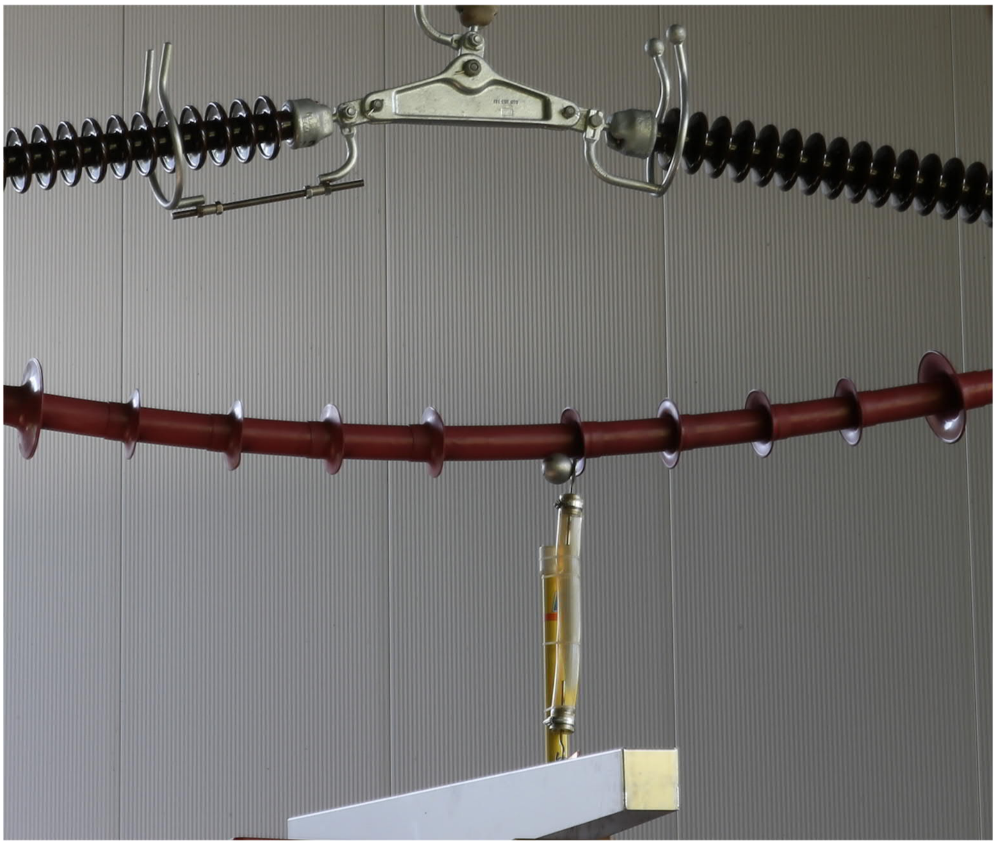
Even in the worst case, audible partial discharges (PD) but no visible PD occur in daylight. The evaluation of the parameters is shown in Table 4. Data for the effect of impulse currents on human body of the impulse shape 10/350 µs are available from the literature [6]. For a bird, the parameters determined in the test are far below the permissible limit values for humans. It can therefore be concluded that birds which come between the ISC and the crossarm will be scared away and will not risk their life. Converting an overhead line to ISC thus contributes to environmental protection. Nevertheless we need to mention, that limits for bird death from electric shock are not currently standardized and may be the subject of research.

Table 5 Test results

Test	**Applied Voltage line to ground**	**Peak current I and wave shape**	**Specific Energy** $\int i(t)^2 dt$	**Charge** $\int i(t) dt$
S = 5 cm	71 kV	0,05 A; < 1 µs	0,1 µA²s	10 nAs
S = 0 cm		5 A; 10/100 ns	50 µA²s	10 µAs
Reference				
Limit for human being [6]		2 A; 10/350 µs	1 mA²s	1 mAs



A: Test with clearance s = 5 cm between silicone surface and sphere



B: Test with contact of sphere on silicone surface

a Grounded metallic crossarm
b Insulated support
c Water resistor 4,9 kOhm
d Metallic sphere 5 cm diameter
e Variable corona shield for insulation coordination test
s Clearance

Fig. 11 Test arrangement for bird test

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