

**365**

**ON THE USE OF POWER ARC PROTECTION DEVICES  
FOR  
COMPOSITE INSULATORS ON TRANSMISSION LINES**

**Working Group  
B2.21**

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# On the use of power arc protection devices for composite insulators on transmission lines

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*\* In memory of C. de Tourreil, with whom the work on this project was started in 2005.*

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## TABLE OF CONTENTS

|      |                                                                                                        |    |
|------|--------------------------------------------------------------------------------------------------------|----|
|      | INTRODUCTION                                                                                           | 3  |
| 1    | THE PHENOMENON POWER ARC                                                                               | 3  |
| 1. 1 | POWER ARC IGNITION                                                                                     | 3  |
| 1. 2 | TERMS AND TEMPERATURES DESCRIBING A POWER ARC AND PHYSICAL PRINCIPLE OF A POWER ARC PROTECTING DEVICE  | 3  |
| 2    | INFLUENCE OF THERMAL AND MECHANICAL EFFECTS OF POWER ARC TO THE DESIGN OF POWER ARC PROTECTION DEVICES | 5  |
| 2. 1 | GENERAL CONSIDERATIONS FOR COMPOSITE LONGROD INSULATORS                                                | 5  |
| 2. 2 | EXAMPLES OF THERMAL EFFECTS OF POWER ARCS                                                              | 5  |
| 2. 3 | DESIGN RULES FOR POWER ARC PROTECTION DEVICES                                                          | 8  |
| 3    | DESIGN EXAMPLES                                                                                        | 12 |
| 3. 1 | APPLICATION OF ARC PROTECTION DEVICES DESIGNED FOR CAP AND PIN STRINGS ON COMPOSITE INSULATORS STRINGS | 12 |
| 3. 2 | COORDINATION BETWEEN CORONA AND POWER ARC PROTECTION                                                   | 13 |
| 3. 3 | LIMITS OF SOLUTIONS OF DIRECT ATTACHMENT OF POWER ARC DEVICES TO INSULATOR END FITTINGS                | 14 |
| 3. 4 | ORIENTATION OF POWER ARC PROTECTION DEVICES                                                            | 15 |
| 4    | GENERAL RECOMMENDATIONS                                                                                | 17 |
| 5    | SUMMARY                                                                                                | 17 |
| 6    | REFERENCES                                                                                             | 18 |

## INTRODUCTION

The requirement for power arc protection devices is dependent primarily on the network parameters and secondarily on the insulator types, which are cap and pin, porcelain longrod or composite longrod. Essential network parameters are short circuit magnitude, short circuit duration and frequency of occurrence of power arc events. These factors can lead to design rules that determine if power arc protection is required or if only corona protection has to be taken into consideration. The paper deals with thermal effects of power arcs, design rules of power arc protection devices, applied test philosophies and practical examples. Another aspect is the coordination between corona and power arc protection in cases in which both are required. The paper is considered as supplement to previous publications of the Working Group in this matter /1/, /2/, /3/. In addition to composite insulators, the behaviour of cap and pin as well as porcelain longrod insulators is used as a reference.

## 1 THE PHENOMENON POWER ARC

### 1.1 POWER ARC IGNITION

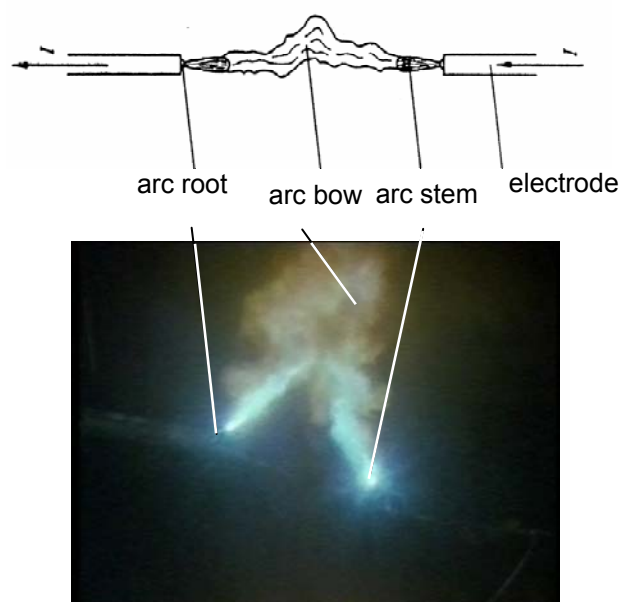
The reasons for power arc events in an overhead line can be:

- Overvoltages due to a direct lightning strike, switch operations or back flashover, which cause air breakdown between the metal parts that form the lowest striking distance e. g. directly between the ends of arcing horns.
- Pollution flashover at nominal voltage (in case of an isolated earth fault) or line to ground voltage. Beside a spontaneous flashover, pollution flashovers often develop from partial arcs formed across the insulator shank. These partial arcs have a  $U-I^x$ -characteristic, which can form a complete power arc when moving away from the shank towards the shed edges.
- Conductor approach due to wind or reduced electric strength of atmosphere in the case of fires under spans.

The first and second reasons are in direct relation to the string insulator design, while the third reason is dominated by the overall line design and special conditions respectively.

### 1.2 TERMS AND TEMPERATURES DESCRIBING A POWER ARC AND PHYSICAL PRINCIPLE OF A POWER ARC PROTECTING DEVICE

The power arc event can be illustrated as in Figure 1. Thermal effects are the main reason for damage to an insulator set. In contrast to internal power arcs of encapsulated equipment, mechanical influences - such as the shock waves caused by the explosion - have no impact. This was proven by high speed recordings, which showed that the damage occurred after a certain exposure time of the insulating material or of the metal hardware to the power arc.



The highest temperature is measured in the area of the arc roots. Depending on the shape of electrode, electrode material, arc current and arc duration, the temperature value can be up to 18000 K in the arc root and 6000 K in the arc stem. The arc bow tends to expand, which creates a larger surface area for interaction with the surrounding atmosphere. The temperatures are lower than in the arc root and the arc stem and the bow

Figure 1: Schematic of a 31 kA-power arc across a 145 kV-tension insulator

moves under the action of electromagnetic forces, wind and thermal up-lift. The risk for the insulator string is mainly due to the arc root and the arc stem. This was confirmed by tests on porcelain longrods /4/, where the arc bow touched the porcelain body. Under the specific test conditions, which included a current limit of 24 kA, a porcelain failure due to direct impact of the arc bow required up to 3 seconds of exposure time. The typical destruction within some hundred milliseconds was due to thermally caused cracking by heat transfer from the metal end fitting to the porcelain body or direct heat transfer from the arc root and from the stem. The power arc value depends on the network and insulator position along the overhead line. For a given arc value and burning duration within the circuit breaker reaction time, the design of the arc protection devices must be able to take the thermal stresses of the root and of the stem away from the insulator string parts which are susceptible to thermal damages.

In view of these basic considerations, the purpose of an arc protecting device can be described as follows:

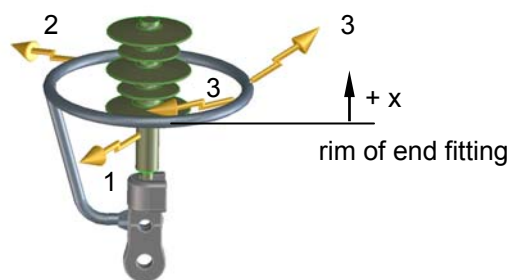


Figure 2: Power arc development of a closed ring design

The arc protecting device should take the arc root immediately after arc ignition and guide it to the final burn-out point, from 1 to 3 (Figure 2). At the end burning point, the power arc should burn in a stable fashion without further movement to the adjacent tower structure or to the conductor until energy interruption. Under the assumption that the power arc is caused by pollution, it will typically start at the insulator end fitting (Position 1). A direct take-over to the arc ring is unlikely because both are at the same electric potential. The arc bow or stem must touch the ring for this purpose. For the power arc take-over, this means that the arc ring position is

preferably towards the other insulator end. The position  $x$  has to be balanced with the insulator design at the triple point in respect to corona optimisation /3/, /5/ and the required striking distance. If the power arc is on the arc ring, it will move to the position 3, driven by electro-magnetic forces. The closed ring of Figure 2 has two disadvantages:

- The power arc direction is unstable and can move towards or away from the insulator string at Position 3.
- A replacement of the ring for maintenance purposes would require a string bypass.

To solve these problems, another principle of ring design is more appropriate (Figure 3). Under the assumption that the arc ignition and take-over is equivalent to that described in Figure 2, the power arc will move towards the end of the ring and jump to the middle horn. In this position, the electro-magnetic forces will guide the arc away from the insulator body. Care has to be taken that magnetic

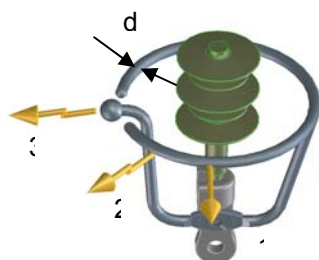


Figure 3: Open ring profile with defined end burning point

fields generated by the currents over the crossarm and tower structures do not act diametrically opposite to the preferred direction of guidance of the ring design.

In contrast to the closed ring, the open ring is more sensitive to mechanical load by weight, which must be considered during installation and maintenance.

The speed of arc movement along the arc ring is also dependent on the diameter of the ring ( $d$ ) and is discussed further in Chapter 2. 3.

## 2 INFLUENCE OF THERMAL AND MECHANICAL EFFECTS OF POWER ARC TO THE DESIGN OF POWER ARC PROTECTION DEVICES

### 2.1 GENERAL CONSIDERATIONS FOR COMPOSITE LONGROD INSULATORS

As it is mentioned in detail below, power arc protection requirements for composite long rod insulators are different from those of “traditional” porcelain and glass insulators. The major differences can be summarised as follows:

- Composite insulators are typically equipped with corona control devices at lower voltages than glass or porcelain strings to meet insulator specification requirements (i. e. ANSI) in respect with Radio Interference Voltage (RIV) and corona. Arc protection devices are often combined with corona control function or corona control devices.
- The corona control requirements of composite long rod insulators have to be designed differently from those of porcelain and glass insulators because of field control along and inside the insulator and the lack of requirement for intermediate end fittings (no section length limitation). Hence, combined corona/arc control devices for traditional strings cannot be used for composite insulators.
- The effects of power arcs are different from those of porcelain and glass because the elastomeric housing has no brittleness under mechanical and thermal shock conditions.

### 2.2 EXAMPLES OF THERMAL EFFECTS OF POWER ARCS

In this chapter, an overview is given of the impact of power arcs on the different insulator technologies. Figures 4.1 - 4.3 show examples of power arc activities on composite insulator strings. In Figure 4.1, a test has been performed on a 161 kV-insulator rated for 120 kN and without arcing horns. A single power arc shot was applied with 50 kA for 0.3 sec as specified by the utility. After exposing the insulator to the arc, the surface was whitened and dusty, but without any detectable damage. The end fittings show certain material loss vaporized or ejected by the arc. In the following tensile test, an ultimate value of 102 kN was measured. Considering a median failure value of approximately 160 kN for

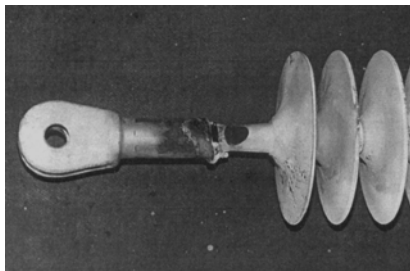


Figure 4.1: End fitting ablation after 50 kA for 0.3 seconds

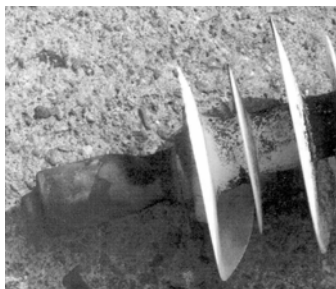


Figure 4.2: Completely burnt 16 mm ball after 31.5 kA-shot sequence 0.2, 0.2, 0.5 seconds



Figure 4.3: Composite post with suitable hardware after 30 kA for 0.5 seconds

virgin composite insulators of this type, the reduction is under these circumstances more than 1/3. However, the insulator still meets the requirements of IEC 61467 /6/, where a residual strength of 80 % of SML-value is specified. It is obvious that a further power arc on this pre-damaged insulator would lead to mechanical failure. Hence, under such power arc rating, the use of power arc protection devices is strongly recommended. Figure 4.2 shows a composite insulator, which was tested in a sequence as specified as per IEC 61467. The composite insulator housing made of Silicone Rubber does not suffer any noticeable damage, but the end fitting, and especially the 16 mm ball, was completely destroyed by the arc root and led to a (mechanical) failure in the test. The ball dimensions are equally specified for all insulator types (conventional and composite) e. g. in IEC 60120 /7/. Under network conditions, represented by these test conditions, the insulator string must be protected with

power arc devices. The protection function of an appropriate hardware design is shown in Figure 4.3. The post insulator was subjected to a power arc with an energy content of 121 MJ. The end fittings of the post are made of aluminum, which needs special care for heat protection. On the arc ring and the end burning sphere, typical arc burning spots are shown. After the “wired” initiation, the power arc was guided directly to the steel hardware and did not contact the aluminum end fitting. The composite post showed no reduction of mechanical strength at all after power arc test.

Several, possible effects of power arcs on cap and pin as well as the porcelain longrod insulators are shown in Figures 5.1-5.6. In the case of porcelain cap and pin or longrod insulators, the glazing can be damaged by the power arc, or if the thermally induced stresses become too high, shattering of the shell can result. As long as the hardware is not consumed by the power arc as shown above, the mechanical integrity of cap and pin strings is less compromised. The effect of inappropriate arc protection to a porcelain longrod is shown in Figure 5.3. Under the test conditions, the power arc destroyed the sheds in the vicinity of the metal end fittings. Figures 5.4-5.6 shows possible damages to glass cap and pin insulators.



Figure 5.1: Burnt glazing /8/

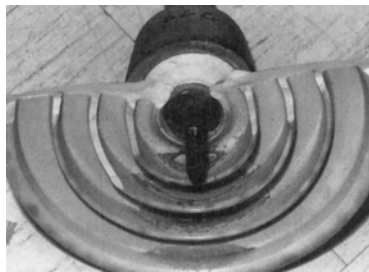


Figure 5.2: Shattered shell /8/



Figure 5.3: Results of different arc protection



Figure 5.4: Damage on a glass disc /9/



Figure 5.5: Burnt ball and shattered glass /9/



Figure 5.6: Molten end fitting and cement /9/

A short overview of the different technologies in respect to their line performance and power arc performance is given in the following Table 1:

| Subject                                                                            | Porcelain Long Rod<br>Cap and Pin Toughened Glass<br>Cap and Pin Porcelain                                              | Composite Longrod                                                                                                                            |
|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| Probability for Pollution-related Power Arc <sup>1)</sup>                          | high                                                                                                                    | low, because of hydrophobicity <sup>2)</sup> and smaller average diameter                                                                    |
| Probability for Lightning Flashover                                                | equal for same striking distance, power arc ignition between shortest striking distance                                 |                                                                                                                                              |
| Thermal Damage of the Insulator Body, if Power Arc <sup>3)</sup> is not controlled | cracking or shattering of insulating body possible                                                                      | no cracking, no critical material loss for most flame and tracking resistant materials <sup>4)</sup>                                         |
| Mechanical Function of Insulator Body for uncontrolled Power Arc                   | Mechanical integrity is compromised if the used cement is aged and gets an irreversible strength reduction by the heat. | Mechanical integrity is compromised if the rod TG <sup>5)</sup> is exceeded leading to stress relaxation of the fitting assembly to the rod. |
| Electrical Function of Insulator Body for uncontrolled Power Arc                   | Reduction of flashover voltage for strings with damaged individual insulators.                                          | Possible damage of housing integrity <sup>6)</sup> has to be considered. If inappropriate materials are used, conductive residues possible.  |
| Mechanical Function of Insulator End Fitting for uncontrolled Power Arc            | Failure possible (e. g. Figure 5.5)                                                                                     | Failure possible (e. g. Figure 4.2)                                                                                                          |

Notes:

- 1) under the assumption that the in-situ conditions can cause flashover
- 2) if hydrophobicity is maintained (recovery, transfer)
- 3) Power arc duration and intensity is sufficient for damage
- 4) such as Silicone Rubber or EPDM with ATH filler, typical V0-rating as per IEC 60707 /10/
- 5) Glass Transition Temperature /11/
- 6) critical interfaces are sealing joints and exposed insulator rod

Table 1: Overview on line and power arc performances of the different insulator technologies

The examples show that all insulator technologies can suffer from power arcs, when not being appropriately protected against the local power arc conditions. The main difference is that they can be damaged in different ways, due mainly to the brittleness of glass and porcelain versus an elastomeric housing.

Service experience has shown that with the use of composite insulators, especially with silicone rubber housing, the risk for a **pollution flashover** can be reduced in comparison to conventional insulator strings, even without applying maintenance cycles.

The risk for **overvoltage flashover** is mainly influenced by the in-situ conditions such as incidence of lightning strikes, efficiency of strike protection or ground resistance (back flashover), and not by the insulator technology for equivalent striking distances.

## 2.3 DESIGN RULES FOR POWER ARC PROTECTION DEVICES

### 2.3.1 MATERIALS FOR POWER ARC PROTECTION DEVICES

This chapter covers some empirically found design rules for appropriate power arc performance of insulator strings. The control of power arcs is also essential for the behaviour of circuit breakers and other electrical equipment. For this reason, many investigations and basic research studies have been made. In respect to the speed of arc root movement along a metal conductor, a general relation was found with  $v \sim d^x$ . In [12], the empirical relation is given for steel for an arc current of 1 kA and a 25 mm electrode distance with  $x = 0.6$ . This follows the “model of area conductors”, the larger the diameter the more “vagabonding” current components can reduce the speed of arc root movement. The advantageous small diameter has to be balanced with the corona performance [5] and the current load capability as well as the melting performance of the power arc protection device.

For the current load capability, there have been two limits defined for galvanized steel [13]:

- Parts, within an insulator string, which directly participate in load-carrying should not exceed  $70 \text{ A/mm}^2$  (related to 1 second)
- Other parts of an insulator string such as arcing devices and others should not exceed  $80 \text{ A/mm}^2$  (related to 1 second)

These values were validated by measurements, the value  $70 \text{ A/mm}^2$  corresponds to a temperature of  $400^\circ\text{C}$  at an environmental temperature of  $35^\circ\text{C}$ . The values as current densities are valid for current flow through the bulk material and not for its exposure to the arc root.

This leads to the differentiation between aluminium and steel for power arc protection devices. The relevant material properties are shown in the Table 2 below:

| Material | Density in $\text{g/cm}^3$ | Melting point in $^\circ\text{C}$ | Combustion heat in $\text{kJ/g}$ | Melting heat in $\text{Ws/cm}^3$ | Heat conduction in $\text{W/(Kxcm}^3)$ | Tensile strength in $\text{N/mm}^2$ | Specific electric resistance in $\text{V/Axcm}$ |
|----------|----------------------------|-----------------------------------|----------------------------------|----------------------------------|----------------------------------------|-------------------------------------|-------------------------------------------------|
| Steel    | 7.85                       | 1500                              | 5.6                              | 2104                             | 0.54                                   | 400                                 | 15E-6                                           |
| Cast Al  | 2.7                        | 620                               | 30                               | 1025                             | 1.88                                   | 200                                 | 4E-6                                            |

Table 2: Properties of steel and aluminium

The table shows the potential of weight savings in the case of aluminium. However, other properties do not make aluminium the first choice as material for power arc protection over steel:

- The speed of arc root movement is higher for steel by empirically determined 50 %. This reduces the thermal effects to the material of the power arc protection devices. For aluminium, the unfavourable combination of lower speed and lower melting point exists.
- The combustion heat of aluminium is five times higher than that of steel. This correlates with a higher heat radiation intensity of burning aluminium as well. The risk for an insulator damage is increased by these facts. Evaporated aluminium can precipitate on the insulator and lead to reduced insulation performance.
- The higher heat conductivity of aluminium would lead to a faster heat transfer into the structure of the bulk material. Due to the low melting point, the aluminium profile can be deformed.

These examples show that the behaviour of an aluminium arc protection device equivalent to a steel design would require more material, which can negate the weight advantage.

The material loss at the end burning point can be calculated for steel with  $0.4 \text{ cm}^3/(\text{kA} \times \text{s})$  /14/. This empirical value depends on intrinsic properties such as heat conduction and melting point. For aluminium, a value of  $1.4 \text{ cm}^3/(\text{kA} \times \text{s})$  is given. If the sphere of the end burning point (Figure 3) is designed for 420 kV, a diameter would be for example 80 mm for RIV requirements of 40 dB. This diameter was empirically determined for a typical 420 kV-suspension string configuration. The 80 mm leads to a calculated value of 675 kA x s as a limit for complete loss. The obvious high redundancy is required to prevent excessive material ablation which would create a compromised sphere shape in respect to RIV/corona. The value for aluminium is significantly lower with 183 kA x s.

These material differences can lead to a different behaviour in service (Figure 6.1 - 6.3). If the aluminium, typically used for devices designed for corona protection only, is destroyed by the power arc, it can become the source of corona and must be exchanged (Figures 6.1 and 6.2).

If the network conditions require the use of power arc protection, steel should be considered, as it will suffer only a small material loss (Figure 6.3, after 30 kA for 0.5 sec).



Figure 6.1: Molten corona collar /9/



Figure 6.2: Molten part of a corona ring /9/



Figure 6.3: Protected aluminium end fitting by steel device

### 2.3.2 POWER ARC VALUE ALONG A TRANSMISSION LINE

This raises the question, why under some circumstances the service record of aluminium rings or collars, primarily used for corona protection, is reported to be sufficient even for power arc exposure. There exists material-specific thresholds of required energy  $(I/A)^2 \times t$  that must be exceeded for a thermal material consumption by power arc. For steel, this is  $5 \times 10^4$  (I in A, A in  $\text{cm}^2$  and t in seconds). For aluminium, this value is lower (estimated  $1.5 \times 10^4$  without consideration of exothermal reaction).

The value of a power arc along a transmission line with an overhead earthwire is highest at the substation positions and becomes lowest in the middle of a line. The distribution of the arc current is

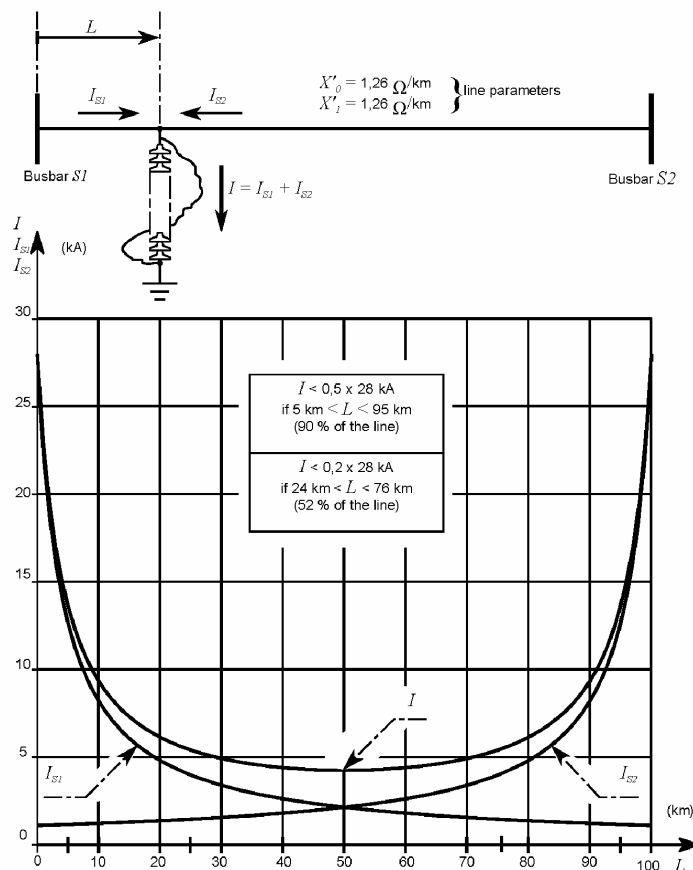


Figure 7: Example of a fault supply current distribution

shown in Figure 7 /6/ on the example of a 100 km long, 145 kV-overhead line which connects two substation busbars with 28 kA of short-circuit current rating. Near the substation busbars (extremity of the line), the short-circuit current is highest and the supply circuit is unbalanced. In the middle of a line, the fault current is significantly lower, however the supply circuit is practically balanced. This balanced situation can cause more severe damages, because of lack of movement of the power arc.

This example shows that certain physical tendencies do superimpose each other and that damages are difficult to predict. It is very likely that the use of aluminium corona rings, especially for composite insulators from 245 kV upwards, has not caused noticeable loss in reliability, because of the reduced likelihood for pollution flashovers (diameter and hydrophobicity effects).

### 2.3.3 APPLIED TESTS

#### 2.3.3.1 TEST OF HARDWARE (INSULATOR STRING) UNDER CONSIDERATION OF CURRENT DENSITY - SHORT CIRCUIT TEST

The short circuit testing with the simulation of the power arc by a high conductive metal conductor is often used for highest current rating (Figure 8.1). Under this test condition, the value and duration of the simulated fault current are not influenced by the power arc movement. The test evaluates mostly the behaviour of the steel parts in the fault current path at a certain specific current density (e. g.  $70 \text{ A/mm}^2$ ). The visual appearances during and after a short circuit test (Figure 8.2) are less “spectacular” in comparison to those of a power arc test. Only the hinges showed a small change of colouration.



Figure 8.1: Short circuit testing



Figure 8.2: End fitting after short circuit testing

### 2. 3. 3. 2 TEST OF STRING DESIGN FOR CURRENT DENSITY AND THERMAL ARC EFFECTS - POWER ARC TEST

The string performance in respect to power arc exposure is more comprehensively tested in real arc tests, for which IEC 61467 gives guidance. In Figure 9, the picture of a high speed record of a 30 kA power arc across a 420 kV-horizontal line post is shown. The power arc was ignited by a short circuit wire. This test scenario provides more information than the short circuit test on:

- forces and current density in the string hardware
- development of power arc
- movement of the arc roots
- impact of heat to the hardware and insulator

The example of an acceptable material ablation of a defined burning point is shown in Figure 6.3.



Figure 9: Appearance of a 30 kA power arc

### 3 DESIGN EXAMPLES

#### 3.1 APPLICATION OF ARC PROTECTION DEVICES DESIGNED FOR CAP AND PIN STRINGS ON COMPOSITE INSULATORS STRINGS

For a given section length, composite long rod insulators often have a shorter striking distance in comparison to cap and pin or porcelain longrod insulators. This is indirectly due to the smaller diameter of the FRP-rod, which is advantageous for the pollution performance. But the required contact area between attached end fitting and rod (by the commonly applied crimp method) reduces striking distance. The application of corona rings either on line or on line and on earth side(s) further reduces the striking distance. This specific fact is well known and does not play a significant role for new constructions or maintenance work without clearance problems, because the length of the composite insulator can be increased correspondingly.

Depending on the philosophy of the utility, insulator strings are often equipped with arcing devices which fulfill corona and arc protection simultaneously. In such cases, the longer end fittings of the composite insulator do not permit the direct interchangeability of the hardware between conventional and composite insulator strings. Such problems do happen sometimes, when stocked material is used, or when projects are awarded for individual items and not as a group of matching items or in the case of projects with conventional and composite insulator options. This is shown in an example for a 245 kV-suspension application (Figure 10.1 - 10.3). In this example, the arc protection devices of the cap and pin string have the so-called racket design on the conductor side, which can be found in many installation cases with cap and pin insulators.

The arrows show the striking distance. In the case of Figure 10.1, the arc is guided to move away from the string, and the shortest distance is between the arcing devices. When using equivalent insulator length for the composite insulator string, the use of the conventional arc ring (racket) would not provide the required performance (Figure 10.2). As the arrow indicates, the arc is in-between the horn on the earth side and the insulator end fitting on the line side. Considering the physical background of Chapter 1.2, there is no reason that the power arc will move towards the racket. A possible solution is shown in Figure 10.3. The line side is equipped with a combined arcing ring and horn. The sphere on top of the horn is designed to meet the RIV requirements, in this particular case with a diameter of 60 mm. This provides sufficient material for the end burning point of the power arc as well. Depending on the RIV-requirements and the expected arc current intensity, the dimensions of the ring and the sphere must be adjusted.

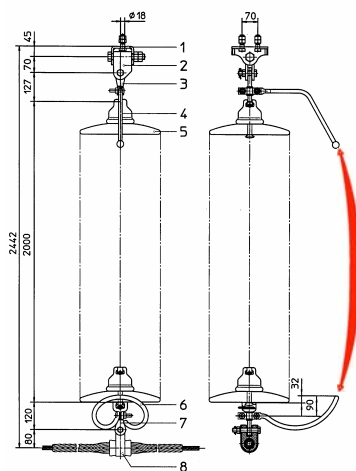


Figure 10.1: Conventional 245 kV-string with racket and horn protection

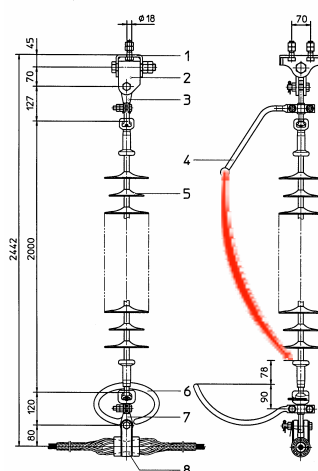


Figure 10.2: Composite 245 kV-string with conventional racket and horn protection

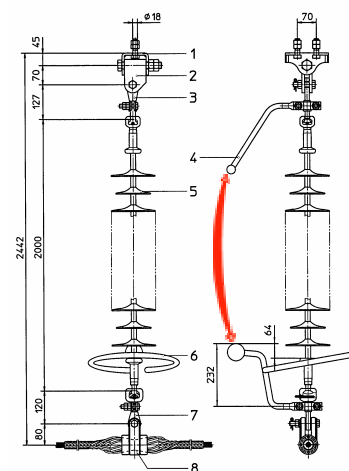


Figure 10.3: Composite 245 kV-string with combined corona/arc protection

The example shows that due to the geometrical difference between cap and pin and long rod design, the power arc protection devices are often not compatible with each other. The power arc device for the composite longrod can be designed to fulfil corona protection requirements without the need for an additional corona ring.

### 3.2 COORDINATION BETWEEN CORONA AND POWER ARC PROTECTION

The importance of coordinated corona and arc protection will be shown on another example of a 245 kV-suspension string design. The design decisions were taken by the client's purchasing department, because of the policy of individual component procurement. Figure 11.1 documents the RIV versus applied voltage and the corona onset positions. The start value of 27 dB is the basic disturbance level at the moment of measurement. The marking in the diagram shows the requirements as per BS 137 /15/, the RIV should be below 40 dB up to 150 kV. This is close to another common design rule, which demands a RIV-approval at  $245 \text{ kV}/\sqrt{3} \times 1.1$ . The measurements showed the inappropriateness of the selected design. From 85 kV onwards, the RIV has a permanent increase. At 151 kV, excessive corona onset took place. The design was rejected because of disturbance and the risk of insulator degradation. For the power arc movement, it is obvious that for an ignition on the opposite side of the horn, the arc would not move to the horn as desired.

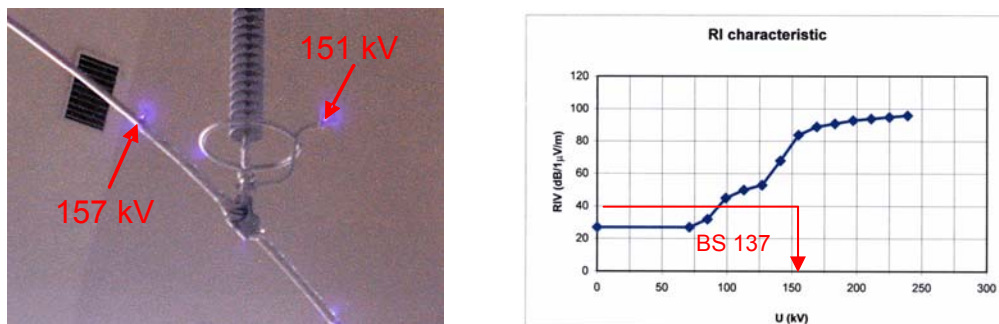


Figure 11.1: 245 kV-string with inappropriate corona protection of arc ring and armour rods

The identical suspension configuration, however with a sufficiently designed corona protection of the power arc protection devices, was tested afterwards (Figure 11.2). The 27 dB is still the basic disturbance level. The first increase of RIV was measured at 190 kV, which is well above 155 kV ( $245 \text{ kV}/\sqrt{3} \times 1.1$ ) and provides a high safety margin. The steep front of the RIV increase is typical for the local, spontaneous corona onset on exposed positions at higher voltage level. The design was accepted to be in line with the specification, also under the consideration of the larger diameter of the ring (higher fault current capability). The horn is on both sides of the ring, hence the power arc would always move towards the sphere.

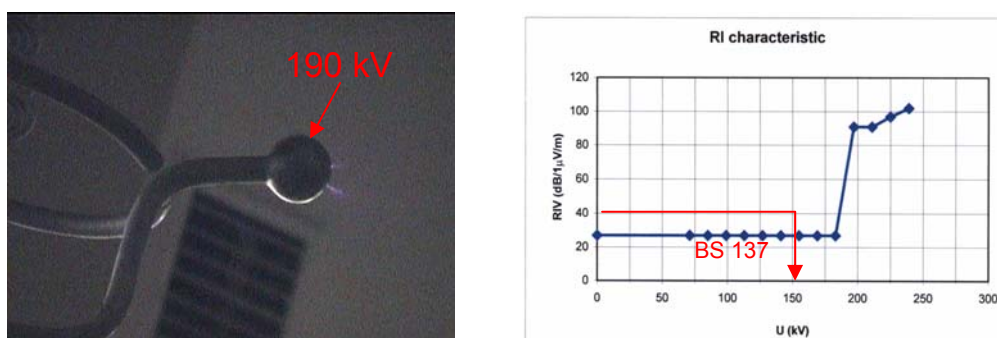


Figure 11.2: Equivalent 245 kV-string with suitable corona protection of arc ring

### 3.3 LIMITS OF SOLUTIONS OF DIRECT ATTACHMENT OF POWER ARC DEVICES TO INSULATOR END FITTINGS

In Figures 12.1 and 12.2, typical solutions are shown for composite insulator strings. Figure 12.1 also corresponds to the introduced configuration, well known from cap and pin and porcelain longrod insulators and proven to work well over a number of years. Due to the slightly longer section length of composite insulators required for identical striking distance to cap and pin strings, compensation for this has been attempted by direct attachment of the ring to the insulator end fitting and not by using the intermediate hardware fitting such as the tongue-tongue link of Figure 12.1.

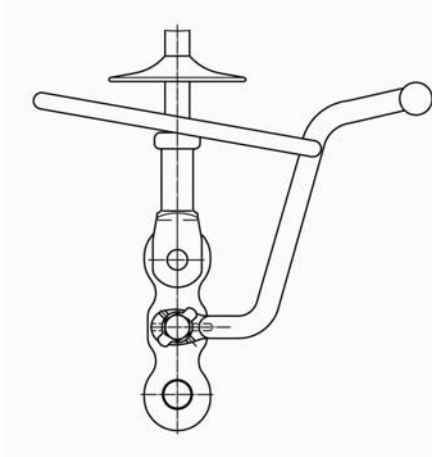


Figure 12.1: Configuration for high power arc current loading

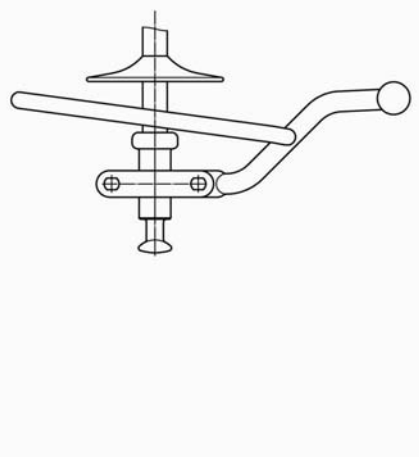


Figure 12.2: Configuration for low power arc current loading

The limitations of Figure 12.2 are as follows:

- The power arc current is limited to around 16 kA in the case of a 16 mm ball (IEC 60120), when the limit of 70 A/mm<sup>2</sup> is applied.
- The power arc current can heat up the end fitting and lead to a reduced mechanical strength for a temperature increase above the specified glass transition temperature of the FRP rod.
- The ring position is less specified without additional measures in comparison to the design using a link adjustment.
- The ring can move due to conductor vibration in the case of insufficiently applied torque of the attachment system.

### 3.4 ORIENTATION OF POWER ARC PROTECTION DEVICES

The power arc protection devices should preferably have an orientation leading to the result that the existing forces during a power arc event support the movement of the power arc away from the insulator. If possible, the end burning point (Figure 3) should not be towards the conductor (Figure 13a). This prevents the power arc from moving onto the conductor or damages by molten steel (Figure 14). An orientation as shown in Figure 13b is ideal, especially when the current  $I_1$  and  $I_2$  are of similar magnitude.

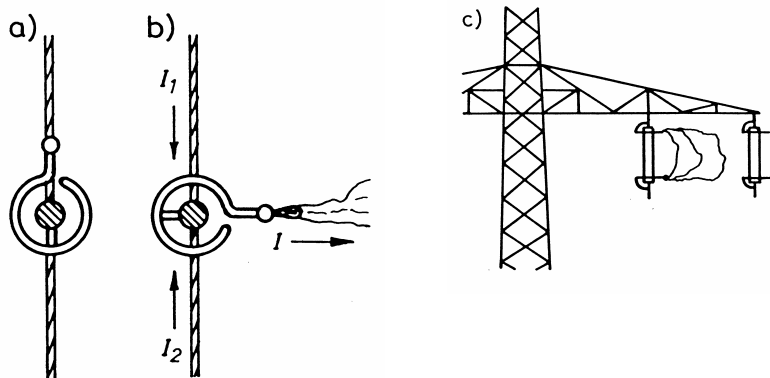


Figure 13 /4/:

- a, End burning point in conductor direction
- b, End burning point transversally to conductor direction
- c, Extension of power arc for long failure duration

The arrangement of Figure 13a might be used in the vicinity of a substation with a main direction of the supply current, however the end burning point can be installed with a small offset to the conductor direction. In the case that the arrangement of Figure 13b is used, a possible flashover across the inner insulator string could cause a flashover of the neighboured insulator string in the case of long failure duration and short phase distance (Figure 13c).

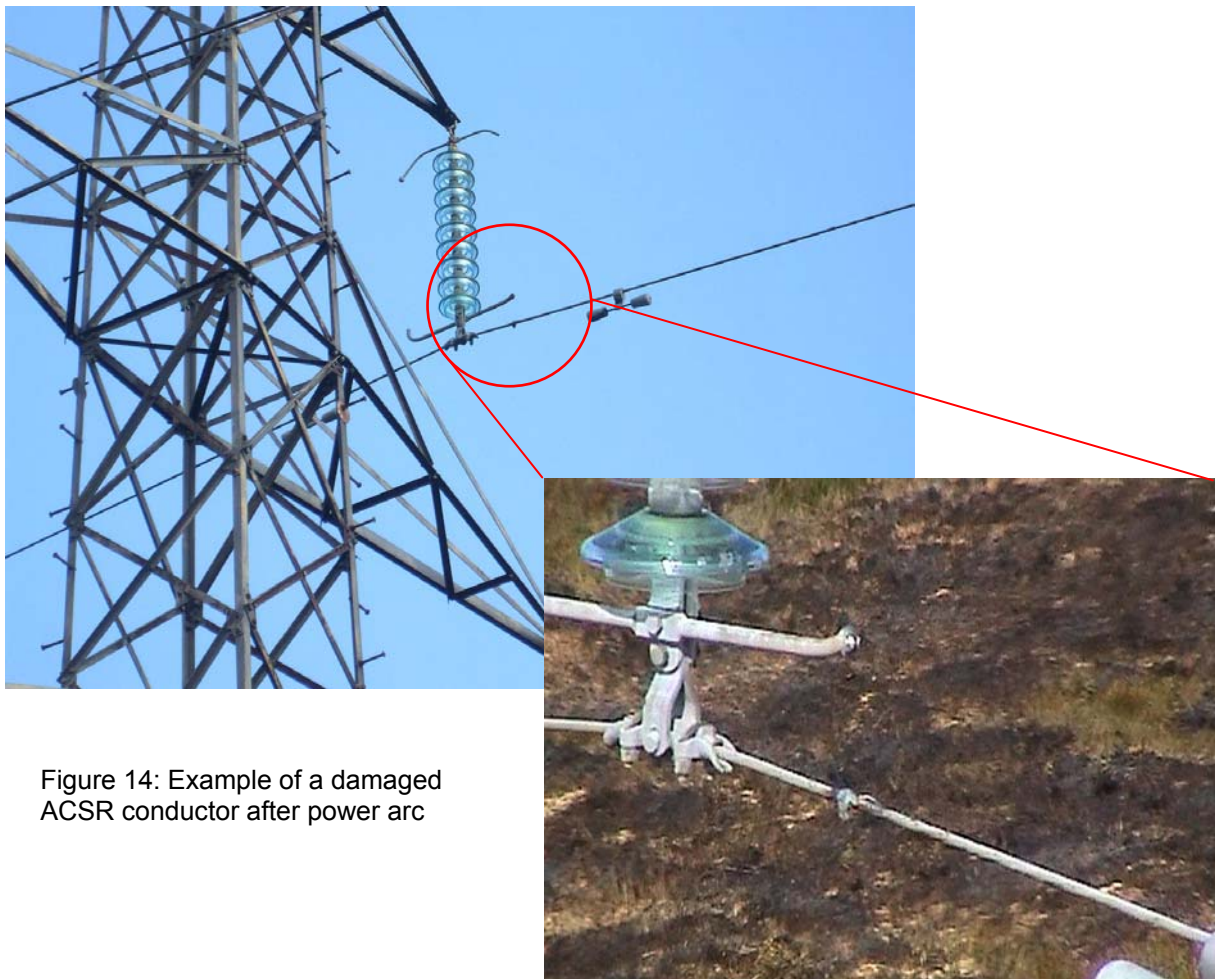


Figure 14: Example of a damaged ACSR conductor after power arc

When double suspension strings are used, the power arc protection devices can be arranged as shown in Figure 15. For V-strings (Figure 16), the V-angle must be considered. The wider the angle the higher the risk that the power arc touches the insulators. A threshold of  $90^\circ$  has been established in Germany [4]. However with the use of composite insulators, a larger angle might be permitted, because the arc bow would not cause thermal cracking of the housing. And materials, which have a high flame resistance (e. g. flammability class V0 [10]) and an appropriate design should not ignite and not be heavily damaged by the power arc. For larger V-angles, the horns are often directed towards the conductor as a compromise.

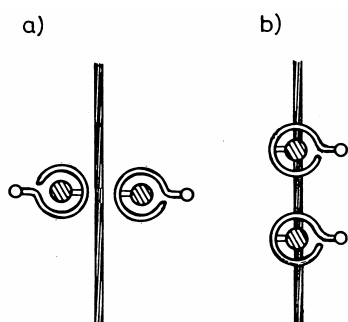


Figure 15: Orientation for double suspension strings

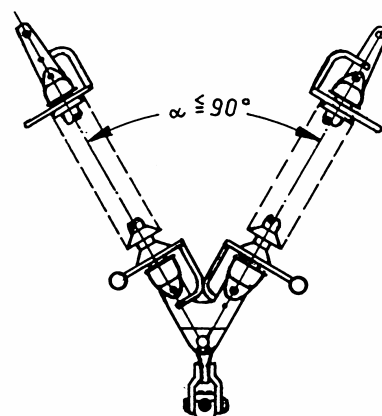


Figure 16: Orientation for V- strings

For dead end or tension sets, the horns points typically upwards, which is the direction of the thermal movement of the power arc (Figure 17).

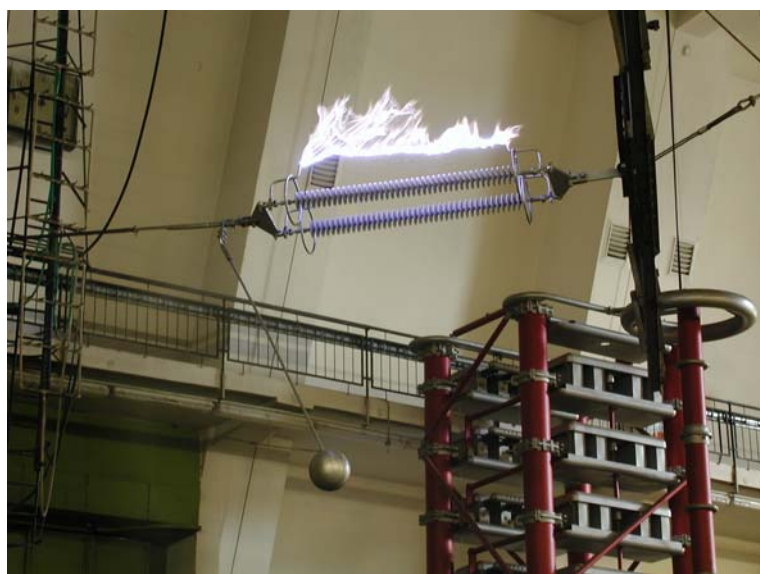


Figure 17: Example of a double tension set with 50 Hz flashover

These examples show that there are no mandatory rules for all situations of string installation along a transmission line. For critical cases, an analysis of the individual string installation might be needed.

#### **4 GENERAL RECOMMENDATIONS**

The available service experience with composite insulators is shorter in comparison to that of conventional insulator technologies. This includes the evaluation as to whether power arc protection is generally required or not. The probability of a power arc in respect to pollution flashover is reduced for a composite insulator that remains hydrophobic during the life time. The probability of flashovers caused by overvoltages is equal for conventional porcelain/glass insulators and composite insulator strings with equivalent striking distances. Composite insulators require more care for corona protection, a typical rule is that from 145...200 kV onwards, a corona ring should be used for the high voltage side /2/. The corona ring can be optimized in this respect to provide both corona and power arc protection as an additional redundancy feature at negligible additional cost. Especially for transmission line level and required power arc protection, both properties must be coordinated. For cost-reduced solutions such as direct attachment to the end fitting, the frequency, duration and power arc value must be evaluated to prevent reduction of the mechanical strength rating of the composite insulator. For the design of power arc protection devices made of galvanised steel, the specific current densities of 70 A/mm<sup>2</sup> and 80 A/mm<sup>2</sup> for parts within an insulator string and for other parts of the insulator string respectively were proven to give safe operation for a normalized fault duration of one (1) second.

#### **5 SUMMARY**

For more than three (3) decades, composite insulators have been used as an alternative to conventional insulators made of glass or porcelain and designed as cap and pin or longrod insulators. Often, the corona protection is combined with a power arc protection for composite insulators using steel devices. The use of aluminium is preferably limited to corona protection. If the testing of insulator strings in respect to power arc performance is made by using the power arc procedure, typical sequences of circuit breaker response to failure case is simulated and the string subjected to the comprehensive stress factors of a power arc event. The recommendation of versatile applicable rules covering all situations of a string installation along a transmission line is not possible. For critical cases, an analysis of the individual string installation might be needed. The document considers actual standards and the long-term experience with composite insulator installations. Reference to the behaviour of conventional porcelain/glass insulators is made to include the long experience with this technology as well.

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