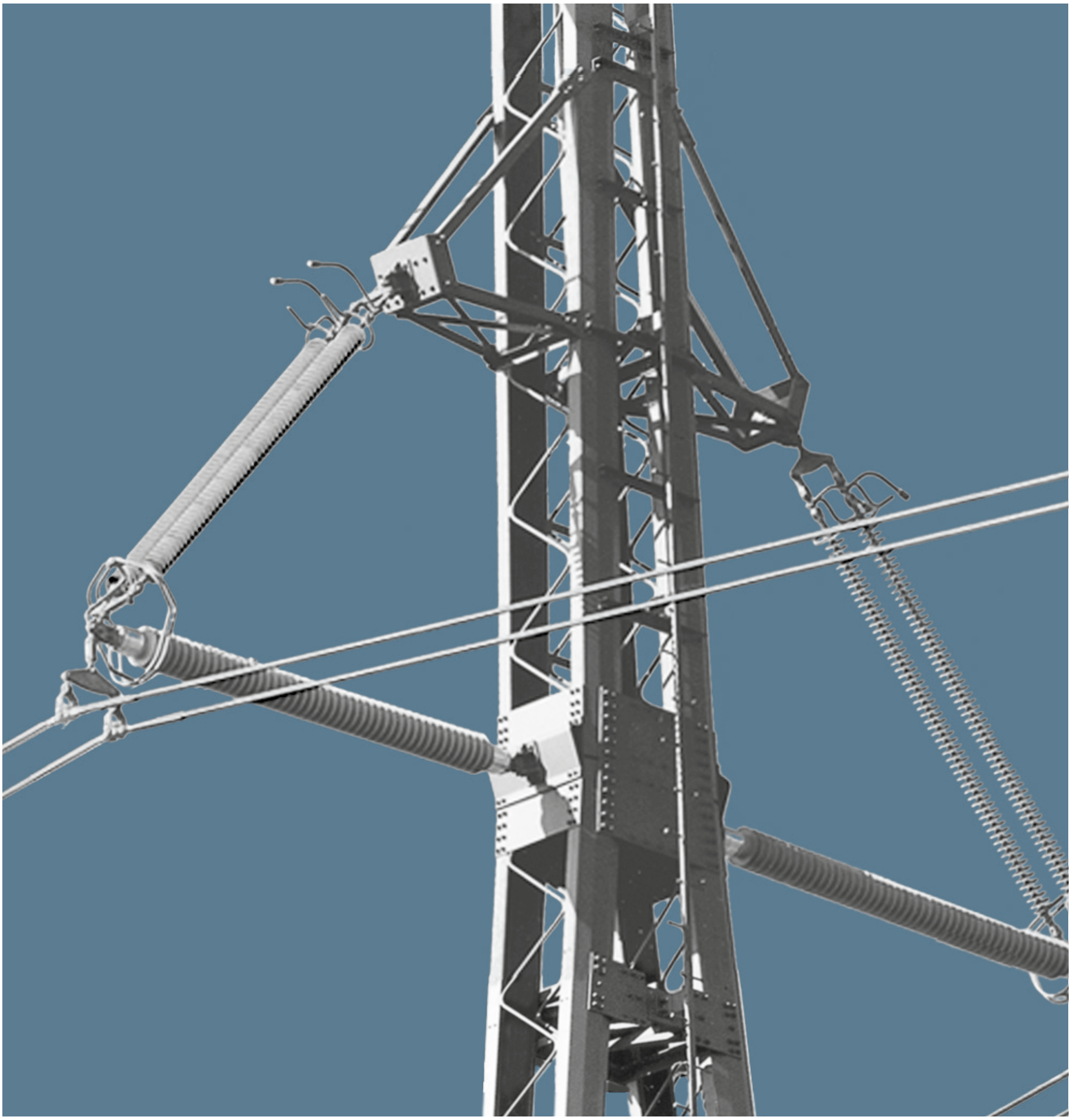
PFISTERER

Technical facts
SILCOSIL© SILICONE INSULATORS

Leading Innovations in Silicone Rubber Technology



www.pfisterer.com

What distinguishes PFISTERER?

PFISTERER Switzerland AG is located in Küssnacht, Switzerland, and has been serving the field of composite insulators for various electrical applications for more than forty (40) years throughout Switzerland and other countries. From the very beginning, PFISTERER has used only Silicone Rubber compounds as the material for the composite insulator housing. The extensive experience in this field has PFISTERER positioned as market leader in the adaptation and use of composite insulations in order to replace the glass or porcelain technologies. This has been achieved through innovations in the Silicone Rubber process technology and as a result of laboratory and service approvals of several Silicone Rubber formulations. The today's unique position of PFISTERER can be characterised as follows:

- Forty (40) years of experience in design and production of Silicone Rubber insulator technology,
- Only Silicone Rubber used,
- Processing of all typical Silicone Rubber grades, optimized for the purpose of application,
- Use of all typical processes of high and low pressure injection moulding and of the modular system,
- Long-term involvement in CIGRE and IEC work,
- Insulator set packages for combined corona/arc protection, proven in worldwide applications.

The Silicone Rubber technology for composite insulators was introduced as a logical addition to complete PFISTERER's products and components that had been manufactured for distribution and transmission installations for fifty (50) years in Switzerland and as part of the German PFISTERER GROUP since 1921.

Since the introduction of PFISTERER's composite insulators in 1975, which are branded as SILCOSIL©, they have been used in a wide range of composite insulator applications at both distribution and transmission voltages. Beside the "classical" suspension and tension application of line insulators, the PFISTERER's service experience includes line posts, braced line posts, station posts, hollow cores and a railway insulator programme. PFISTERER Switzerland AG is certified in accordance to ISO 9001: 2015, ISO 14001: 2015 and ISO 45001:2018.

First Railway Line Installation in 1979

Worldwide First Braced Line Post for 420 kV in 1998

First Suspension/Tension Insulators for 420 kV in 1990

Facts & Figures

1957 Foundation of SEFAG AG "Schweizerische Elektrotechnische Fabrik AG"
1959 Component manufacturing for PFISTERER's product portfolio
1965 Development and manufacturing of components for T&D for the Swiss energy market
1975 Design and manufacture of the first hollow core composite insulator
1978 Joint development of the first composite insulators for Swiss Railways with the company Dätwyler
1979 First installation of railway composite insulators in the Swiss Lötschberg Tunnel
1986 Installation of the first composite insulators in the Swiss Transmission Network
1987 Line hardware department including design and engineering services established
1988 Design and manufacture of SEFAG's insulator set and line hardware programme started
1989 Supply of 420 kV insulator sets and spacer dampers for Middle East
1990 Supply of 420 kV composite insulators for NOK Switzerland
1993 Complete service available for vibration issues including damper and recorder supply, field measurements and analytical investigations
1995 Design and supply of components for 220 kV double circuit line including tubular poles
1997 Complete material supply package for 132 kV line in Ethiopia including towers, conductors and insulators


145 kV Current Transformer in 1998


500 kN Tension Sets for 420 kV in 2004

1997 Supply of 525 kV insulator sets and spacer dampers for South America
1998 Supply of the 1st generation of composite horizontal Vee configuration for the world's first 420 kV compact line in Switzerland
1999 Introduction of polymeric arrester and railway insulator production with Silicone Rubber HTV-technology
2000 Foundation of SEFAG IXOSIL AG, the former Dätwyler AG, extension of LSR capabilities and HV test laboratory facilities
2000 Composite insulators for 400 kV HVDC transmission line of PPC in Greece
2004 Supply of 2nd generation of 420 kV horizontal Vee to Middle East
2007 Supply of 3rd generation of 420 kV horizontal Vee to DEWA in Dubai
2008 Supply of post insulators for 800 kV HVDC Project Yunnan / Guangdong in China
2009 Supply of railway insulators for the 57 km double track of the Gotthard Basis Tunnel
2009 Supply of 500 kV HVDC insulators to Fingrid
2010 Supply of complete insulator sets for TenneT's 420 kV compact line Windtrack in the Netherlands
2012 Supply of complete insulator sets for Energinet's 420 kV compact line in Denmark
2013 Successful testing of a 765 kV Vee configuration
2013 Successful testing of a 420 kV diamond string configuration of the National Grid in UK
2014 Supply of complete insulator sets to ESKOM's 765 kV transmission lines
2018: Merger of Swiss subsidiaries PFISTERER SEFAG AG and PFISTERER Ixosil AG to form PFISTERER Switzerland AG.
2021: PFISTERER celebrates its 100th anniversary.
2021: PFISTERER establishes a new sales and technology centre at Küssnacht am Rigi, Switzerland, uniting the previously separate Swiss sites in Malters and Altdorf.


3rd Generation of Braced Line Post for 420 kV in 2007

Product

Preface

The following description provides an overview of the product "SILCOSIL Composite Insulators" made by PFISTERER. Detailed depictions explain the choice of the materials for a constant and reliable product service perfomance.

Composite insulators were introduced in the late sixties. The basic idea consists of the combination of different materials, which perform different duties in the insulator function corresponding to their particular strength and properties (Fig. 1).
The end fittings are typically made of metal, such as forged steel or aluminium. For line insulators, a high degree of standardisation has been achieved for the end fittings, which enables the easy replacement of existing conventional insulators by composite solutions.
The glass fibre reinforced resin rod is responsible for bearing the mechanical loads, which can be tension, bending or compression, or a combination of all three, depending on the application and load scenario.

Materials for the housing are as manifold as the corresponding methods of manufacturing. However, there are performance trends as a result of the existing service experience, details of which are provided later.

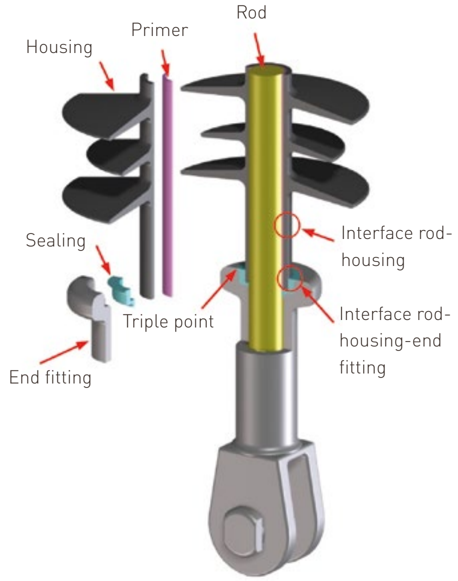


Fig. 1: Parts of a composite insulator

Fig. 2: Typical end fitting designs

End Fitting

Typical end fitting configurations are shown in Fig. 2. Dimensions are in accordance with IEC 60120, IEC 60471 or IEC 61466, as well as equivalent ANSI.

For distribution level up to 70 kN, cast steel end fittings are used. For force ratings above 70 kN, forged steel end fittings are applied. For special applications such as railway catenary line fittings, a high strength coquille aluminium is often used. The steel end fittings are hot dip galvanized. The thickness of the galvanizing follows the recommendations of IEC 60383. Enhanced thickness for heavily corrosive in situ conditions or DC applications can be provided on request. Details of the dimensions and their relation to force rating are shown in the insulator design catalogue.

Rod

The glass fibre reinforced resin rod is an important component of a composite insulator. The rod is typically produced in a continuous pultrusion process. Different diameters are available depending on the application (Fig. 3).

The content of fibres determines the specific intrinsic tensile and bending strength of the rods.

The glass sizing is important for the bond to the resin matrix. The resin matrix itself must be "electrically graded", characterized by low moisture absorption and by negligible change of electrical and mechanical properties. The resin elongation must be balanced with the glass elongation to prevent cracks and fractures when being subjected to loadings. Typically, Epoxy-based resins are used today.

Fillers are used for different purposes, which gives the rod a transparent or opaque appearance. When the raw materials are carefully checked, process parameters are accurately selected and routine checks are determined using statistics, both types of rod offer excellent and reliable performance.

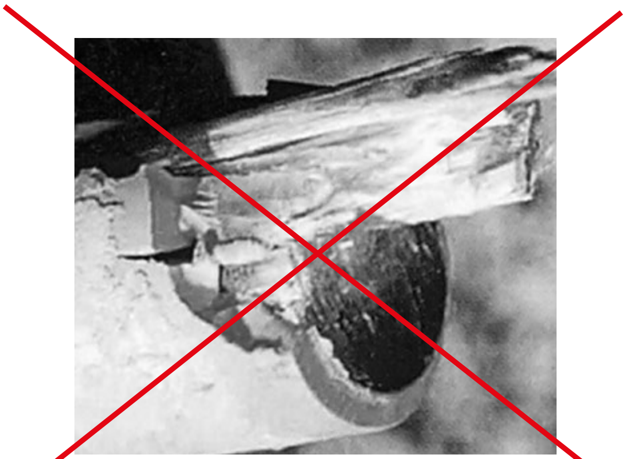


Fig. 4: No BF with E-CR glass

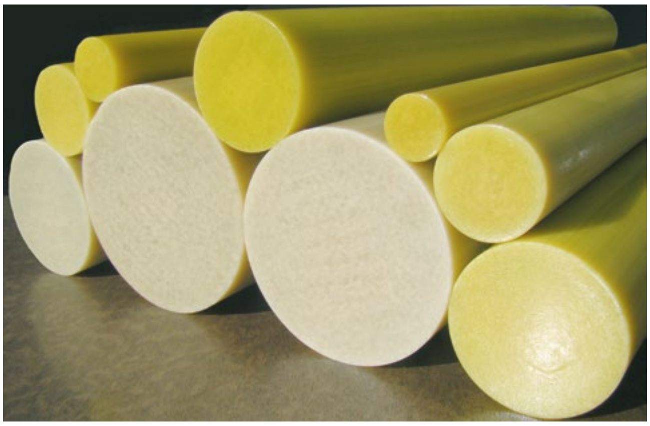


Fig. 3: Example for rod dimensions

Rod for Tension Applications

The glass grade influences the susceptibility to failure by electrolytic stress corrosion (Brittle Fracture – BF). This phenomenon is characterised by a destructive acid attack on the glass fibres, followed by a mechanical insulator failure, when the remaining fibres can no longer bear the service tensile load. Recent investigations in CIGRE and IEEE as well as the service experiences have shown that with specially formulated glass fibres (low or Boron-free content, so-called E-CR glass) the likelihood of a brittle fracture can be significantly reduced (Fig. 4). PFISTERER uses such BF resistant rods.

In IEC 62039 Ed. 1: 2007, a 96 h test is described to prove acid resistance of rods. And with IEC 62662 Ed. 1: 2010, a useful guide is available when assessing the risk of insulators, which belong to an older vintage equipped without acid-resistant rod. The last shows examples of failure mode and effects analysis (FMEA) to assess those factors that make the entire insulator design or string design vulnerable to brittle fractures and provides quantitative figures for a risk estimation on basis of the overall insulator and string design.

Guidance for the design of composite insulators for tension and suspension applications is given in:

- IEC 61109 (Composite longrods)

Rod for Bending Applications

Rod diameters are chosen on consideration of both operational and ultimate cantilever load and permissible deflexion at operational load.

As an advantage of composite post insulators, the so-called safe failure mode has been found. This means that a composite post insulator developed with appropriate design would not fail by part separation after overload, but only by an interlaminar shearing in the neutral zone (Fig. 5).

This safe failure mode has the following performance enhancing advantages compared to porcelain:

- No part separation and no immediate or spontaneous conductor drop,
- Easy detection because of over proportional deflexion,
- High residual strength capability.

Guidance for the design of composite insulators for bending applications is given in:

- IEC 61952 (Line posts)
- IEC 62231 (Station posts)

Note: IEC 62772 for hollow core station posts is under development

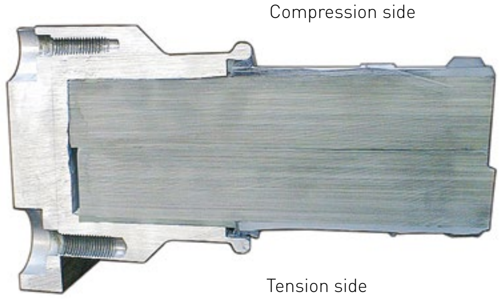


Fig. 5: Cross section of a composite line post after safe failure

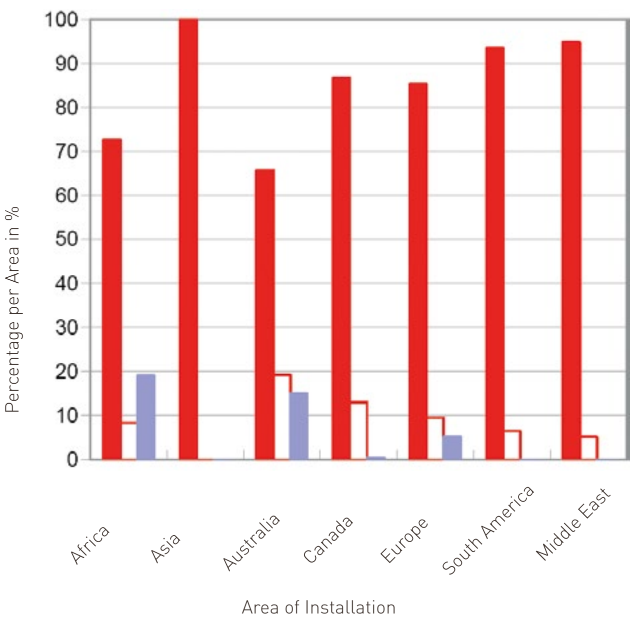


Fig. 6: Use of housing material for composite insulators > 100 kV

Housing

The electrical purpose of an insulator is the insulation of the high voltage potential to ground or between two phases against an external flashover. Simplified, a flashover event can be caused by an overvoltage or by pollution.

With the invention of polymeric insulators, many different materials have been tried and tested in respect to their outdoor service performance. The experience has shown that there exists a close interaction between sole material properties and the overall design of an insulator.

A survey conducted by CIGRE Working Group B2.03 and published in the year 2000 has shown that the majority of composite insulator applications use Silicone Rubber as housing material (Fig. 6). EPDM and others play a less important role.

Meanwhile, the striking distance determines the behaviour during an overvoltage, the shape (geometry) of the insulator and wetting behaviour of the insulator surface become the dominating factors for the pollution performance.

Hydrophobicity as Key Property

Typically, composite line insulators have smaller average diameters than porcelain or glass insulators. As a result, an improved flashover performance is achieved by the shape and by the non-wettability of the surface. Wettability characterises the spreading of water on surfaces, and it can be divided in principle into hydrophilic (Fig. 7) and hydrophobic (Fig. 8).

The service experience has shown that the property "hydrophobicity" is vital for a reliable operation under polluted conditions without precautionary maintenance measures such as cleaning or greasing.

Comparing Silicone Rubber with other polymeric materials as well as glass/porcelain as reference, the following principle matrix (Table 1) can be drawn.

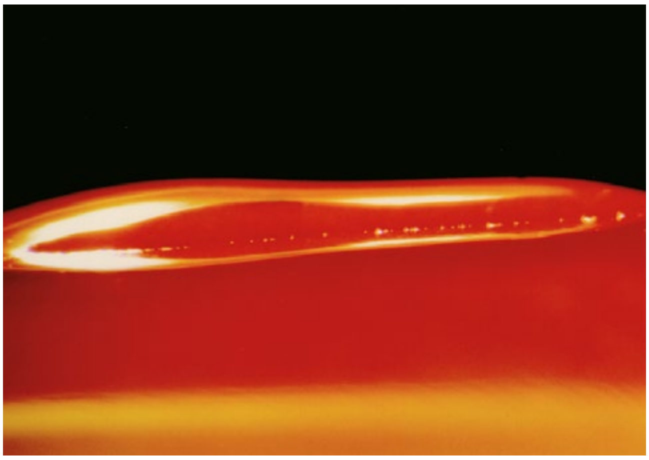


Fig. 7: Hydrophilic surface behaviour

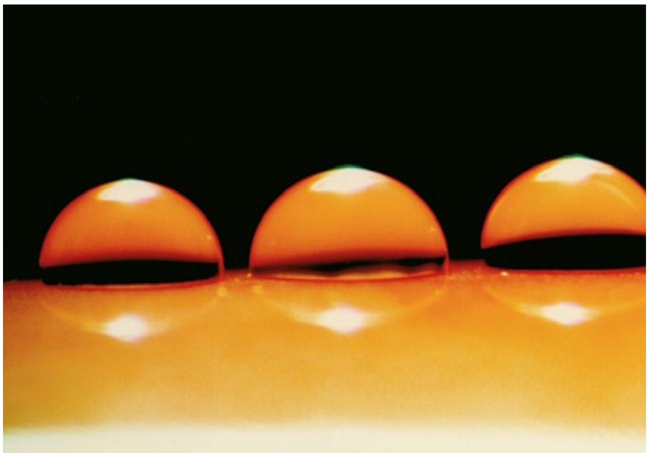


Fig. 8: Hydrophobic surface behaviour

Generic Housing Material	Hydrophobic Surface Behaviour			Hydrophilic Surface Behaviour		
	new	aged	polluted	new	aged	polluted
Silicone Rubber	yes	yes, after recovery*	yes, after transfer**	no	no, only temporary	no, only temporary
Other polymeric Materials	yes	no	no	no	yes	yes
Glass / Porcelain	no	no	no	yes	yes	yes

Table 1: Surface behaviour versus material

* Recovery is a well-documented process of Silicone Rubber and means that hydrophobic properties return mainly by reorientation of the methyl groups on the surface of the bulk material.

** Transfer is the migration of low molecular chain molecules into the pollution layer from the bulk material. In sufficient amounts, the pollution layer becomes hydrophobic and behaves ideally like an insulator without pollution.

Fig. 9: Erosion resistance of inappropriate filled (top array) and well-balanced (bottom array) Silicone Rubber

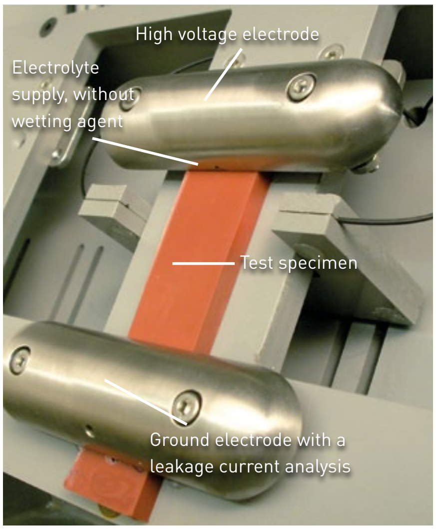


Fig. 10.3: Set-up of the Dynamic Drop Test

Anti-ageing Properties

Regarding the insulating behaviour of composite insulators, the property of hydrophobicity is considered to be the most important factor. The dynamic processes of the hydrophobicity loss and recovery and their strong dependence on material (including basic formulation, filler, and additives) and on processing technology are fields of continuous optimization.
As an example, in CIGRE Working Group D1.14 scientific investigations have been executed, to quantify retention and the transfer of hydrophobic properties into a defined pollution layer. The results were published in the Technical Brochure 442 in 2010.
If the hydrophobicity is lost, the second "defence mechanism" of the material against intensive ageing (bulk erosion, tracking) must protect the insulator. This is preferably evaluated by tests investigating tracking and erosion performance. In this respect, it is welldocumented that High Temperature Vulcanizing (HTV) Silicone Rubber grades enriched with Aluminium Trihydrate outperform non-enriched grades with low viscosity such as Room Temperature Vulcanizing (RTV) and Liquid Silicone Rubber (LSR) grades (Fig. 9).

While in the beginning, the amount of filler was of negative influence to the dynamics of hydrophobicity effects, today's HTV materials combine excellent tracking and erosion performance with a high retention (Fig. 10.1) and short hydrophobicity transfer time (Fig. 10.2).

This can also be shown by a Dynamic Drop Test developed in D1.14 (Fig. 10.3). HTV has the highest resistance of hydrophobicity under the test conditions selected (Fig. 10.4).

Fig. 10.1: Hydrophobicity of an unpolluted Silicone Rubber surface

Fig. 10.2: Hydrophobicity after transfer of a polluted Silicone Rubber surface

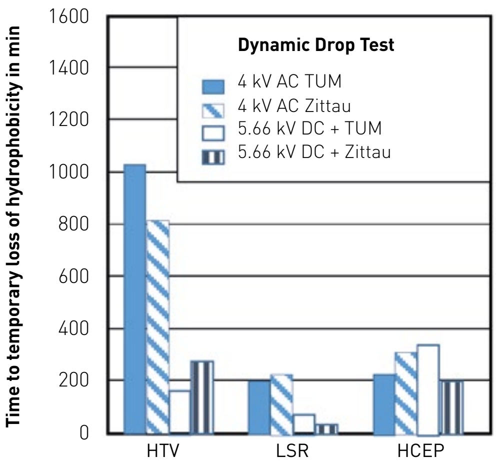


Fig. 10.4: Retention of hydrophobicity of various polymeric materials used for housings (CIGRE Electra 272_3_2014)

As shown in the introduction, PFISTERER's development in composite line insulator technology began with the request from the Swiss railway and for conditions of very high pollution. This is one of the reasons why Silicone Rubber was introduced as the housing material and why the material properties and process technology were further developed on consideration of advancing knowledge in this field, and in addition to feedback from service.

Nowadays, around 95% of insulators are manufactured with HTV-technology. The decisive factor is mainly the superior ageing performance of the corresponding Silicone Rubber system. A comparison of the three used Silicone Rubber grades is shown in table 2.

Property	HTV* Silicone Rubber	RTV/LSR** Silicone Rubber
Viscosity	 30...45 Mooney (pasty)	 30,000...150,000 mPa
Ageing Performance		
Tracking/Erosion	High	Average
UV-Resistance	High	High
Flame Resistance***	High	Average...High
Acid Resistance	Average...High	High
Hydrophobicity		
Recovery	Fast	Fast
Transfer	Fast	Fast

Table 2: Comparison of properties of different Silicon Rubber grades

* HTV = High Temperature Vulcanizing
** RTV = Room Temperature Vulcanizing, LSR = Liquid Silicone Rubber
*** Material property e.g. important for power arc performance and fire load situations

Components and Quality Control

Preface

The following explanations cover the manufacturing processes and associated quality control for composite insulators at PFISTERER. This is divided logically between the components and the applied processes.

End Fitting Component

The end fittings are typically supplied in large volumes; hence statistical methods are used to check the quality on a number of specimens which are considered to be representative of the supply (Fig. 11).

The properties to be tested and approved are as follows:

- Volume,
- Main dimensions,
- Steel composition,
- Hardness,
- Galvanizing thickness,
- Internal surface.

Fig. 11: End fittings as bulk volume

Rod Component

The rods are manufactured with the continuous pultrusion process (Fig. 12). This method has been perfected with the growth of the composite insulator technology and today offers highly efficient production combined with products that meet the high quality required for electrical applications.


Fig. 12: Modern pultrusion machine

Automated dosing systems for the resin composition and temperature control for polymerisation guarantee the continuous reproducibility of the rod properties.

A wide range of diameters is available, selected in accordance to the specification of the application.

Typical rod diameters for longrod insulators range from 14...38 mm and from 38...170 mm for post insulators.

Each rod batch is tested and samples are taken randomly. Typical properties to be checked are:

- Volume,
- Main dimensions,
- TG* measurement,
- Glass content,
- Capillary test (Fig. 13).


Fig. 13: Quality control of rods

* Glass transition temperature

Components / Processing and Quality Control

Silicone Rubber Component

The Silicone Rubber is the component with a specific expiry date. For this reason, the first-in-first-out principle has strictly to be followed.

Each batch comes with a certificate, which contains the relevant physical data measured on samples of uncured Silicone Rubber.

For this reason, specimens are vulcanised from each batch and the erosion resistance and the hydrophobicity are individually and automatically measured. The test equipment (Fig. 14) for this receiving inspection was directly developed from the current activities of CIGRE Working Group D1.14.

Fig. 14: Testing of Silicone Rubber

Crimping Process

Controlled machines with eight jaws (Fig. 15) are state-of-the-art crimping process machines. The crimp machines used by PFISTERER have three independent integrated control mechanisms:

- Crimp pressure,
- Travel distance of moving jaws,
- Acoustic emission.

For each metal grade (steel, aluminium etc.) and each combination of end fitting and rod diameters, an empirically established field of crimp parameters is applied. When commissioning new machines, great care is taken in their calibration to guarantee the applicability of the introduced and well-established crimp parameters.

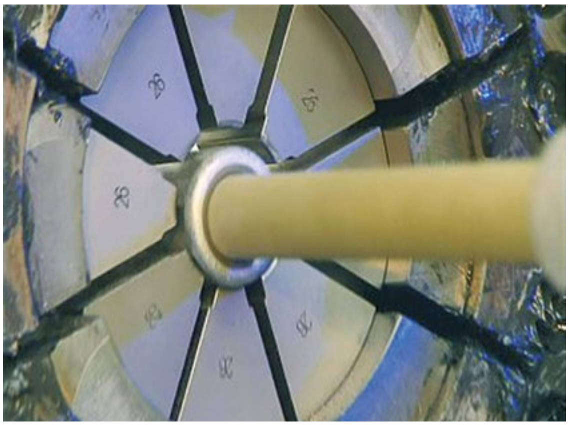


Fig. 15: View onto the crimp jaws

Components and Quality Control

In addition to the integrated control, the acoustic emission method is used as a tool, which operates independently from the machine. This system was developed on an empirical basis: the statistically determined record of noise patterns for certain crimp scenarios provided the limits for given material combinations. From these results, the thresholds with appropriate safety margins were deduced.

To simplify the work regime for the crimping process, the data as shown in Fig. 16 are stored on a hard disk and the operator receives a simple visual confirmation for approval of the crimp process with a red or green bar (correct crimp).

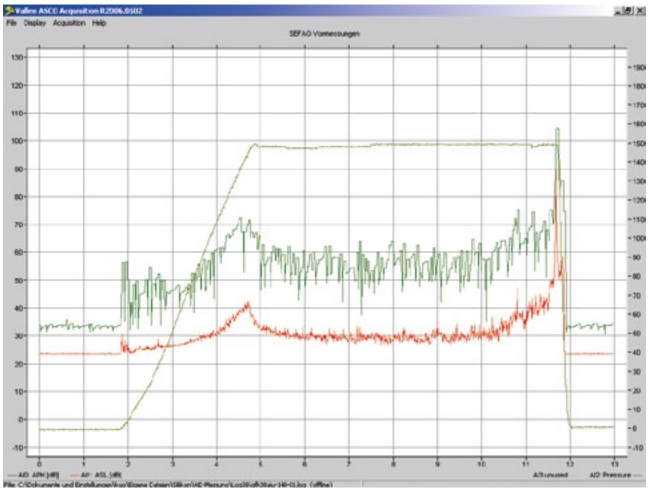


Fig. 16: Screen shot of an overcrimp situation

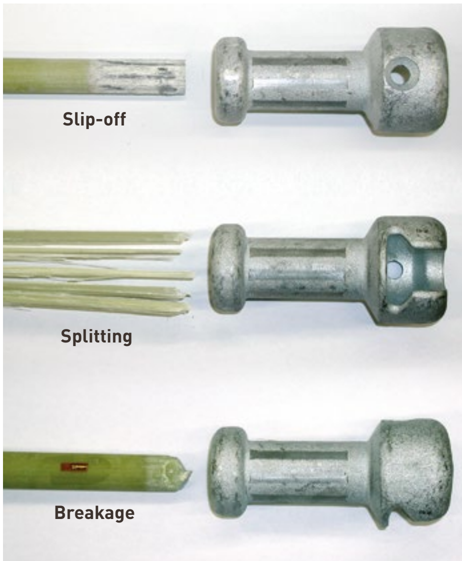


Fig. 17: Failure modes of the interface between rod and end fitting

The interface between rod and end fitting is decisive for the long-term functionality of the insulator in service. The possible failure modes (Fig. 17) for identical rod and end fitting configuration result in different ultimate values and their dispersion. It was found out that a design in accordance to the slip-off mode provides the most stable reproducibility of the ultimate failing load and its dispersion. For this reason, PFISTERER SEFAG follows this design philosophy, which includes that the ultimate tensile load is around 20 % higher than the Specified Mechanical Load (SML).

A failure by splitting indicates that a notch effect is caused as a result of the deformation in the crimp process or as a result of the internal design of the end fitting. On the other hand, a failure by breakage is an unambiguous indicator of over-crimp. This failure mode can be detected by measuring acoustic emissions.

The measurement of ultimate tensile forces is always a statistical process with a certain dispersion of the individual values. For this reason, the application of mathematical models is suitable for trend analysis. Using a Gaussian function (normal distribution function), the difference between the ultimate tensile forces and their dispersion for different crimp scenarios can be quantified (Fig. 18). Crimping of identical dimensions and materials but with optimized parameters (red) provides significantly higher values and reduced dispersion. It is worth mentioning that the higher values of the optimized crimp process do not show any reduction in the time-load test, which is typically applied to verify the time-dependency of the design (96 hour test philosophy of IEC 61109).

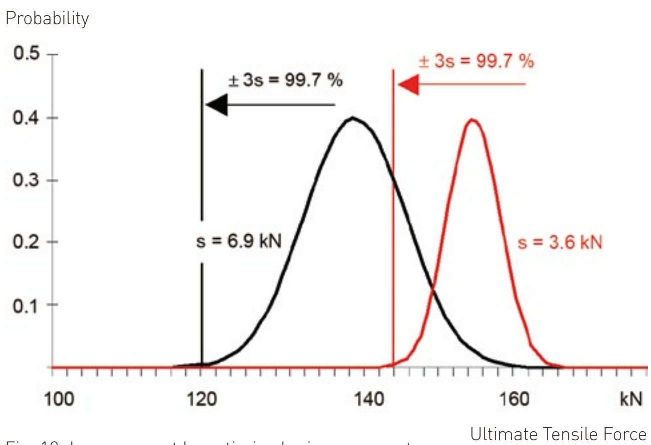
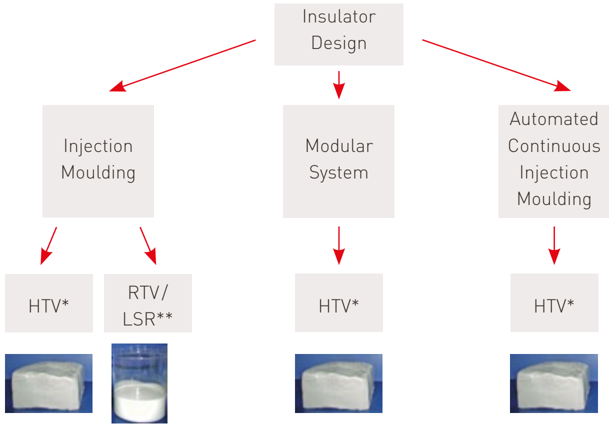


Fig. 18: Improvement by optimized crimp parameters

Housing Manufacture Process

Because of the long-term involvement in Silicone Rubber processing for electrical applications, PFISTERER has adopted and developed a number of process technologies to meet market requirements for special applications with smaller volumes and bulk volumes for highly standardised types of insulators. The processes and Silicone Rubber grades used can be distinguished as shown in Fig. 19. The optimisation of the material properties and the related process parameters are carried out on careful analysis of the feedback from service. The results clearly show that housings made from HTV Silicone Rubber are to be preferred.



*   using high pressure injection moulding
** using low pressure injection moulding
Fig. 19: Silicone Rubber processing used at PFISTERER

Injection Moulding Process

The high viscosity of the preferred HTV-Silicone Rubber system requires high pressure injection moulding. The typical range of pressure is 1,500 bar and above. The process of injection moulding enables efficient bulk volume production but, however, sophisticated processing and corresponding tools are required due to the combination of high pressure and high temperature. Moulding can be made in one or multiple steps (Fig. 20); multiple steps optionally offer a discontinued mould line along the insulator.

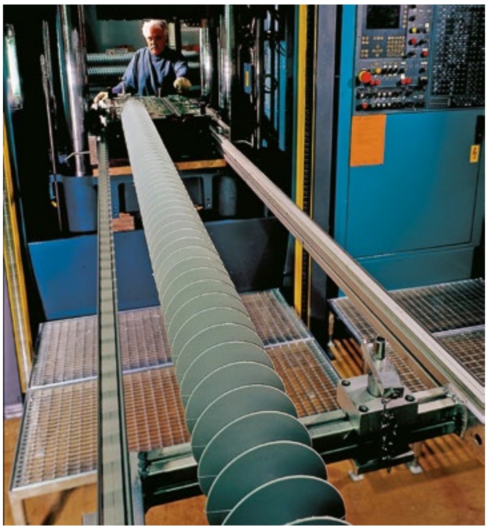


Fig. 20: Multiple high pressure injection moulding

The relatively low viscosity of RTV/LSR-Silicone Rubber systems requires significantly lower injection pressure in comparison to HTV. For simple parts, "gravity" moulding is applicable (Fig. 21). Due to the simpler requirements, PFISTERER uses RTV/LSR-systems as a time efficient compromise especially for prototyping or special applications, which require soft Silicone Rubber behaviour.

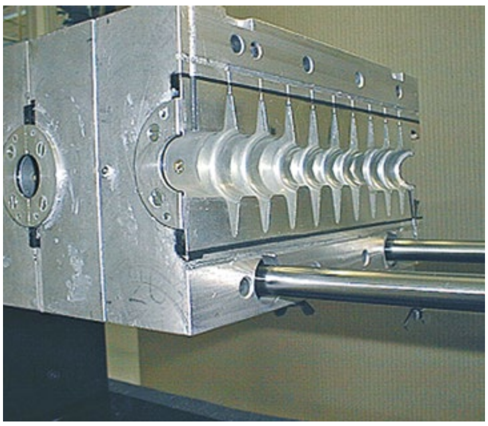


Fig. 21: Die for low pressure injection moulding

Owing to the fact that the lack of filler results in a combination of an axial mould line and lower erosion performance, PFISTERER does not recommend this Silicone Rubber system for critical pollution and the transmission voltage level. The higher the applied voltage, the more non-uniform (nonlinear) the voltage distribution along the insulator becomes. The risk for partial discharges in the mA-range, which burn stable across dry bands, increases and might require a correspondingly high erosion resistance.

Modular System Process

The modular principle was invented in the early sixties and has been continuously perfected since then. It combines the advantages of the HTV-Silicone Rubber technology with the high flexibility of easy adaptation to specific insulator dimensions (especially the ratio between creepage and striking distance – Fig. 22). As a result of having several pre-processes for the "modules", this process cannot directly compete with injection moulding in terms of cost, despite a high degree of production automation for the individual processes (Fig. 23).

Nowadays, the modular principle is considered as an excellent supplement to the production of standard insulators and serves as a suitable, proven alternative method for DC applications requiring high creepage distance. Furthermore, this process is typically used to produce for special applications and low volume orders with limited use where major tool investments are not justified. For applications in which sheds with underribs are required or preferred, this design feature can be easily met by the modular system.

PFISTERER uses this process for all typical insulator applications:

- Suspension/tension insulators,
- Post insulators,
- Hollow core insulators.

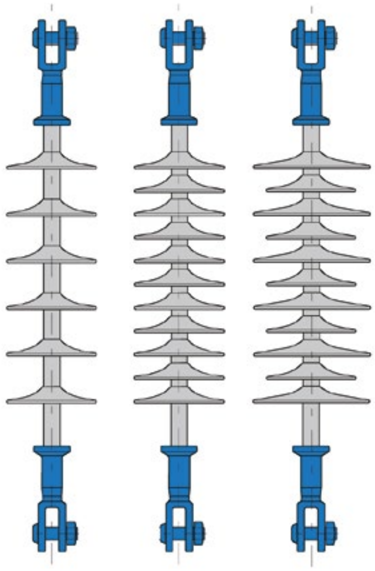


Fig. 22: The advantage of "Modular"

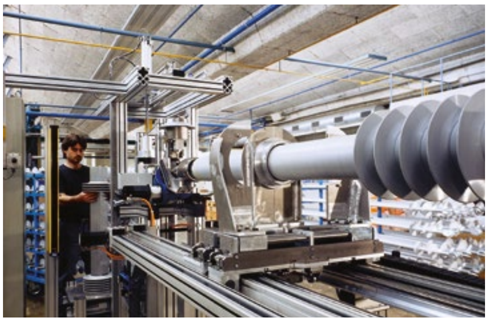


Fig. 23: Modular assembly robot

ACIM Process

The Automated Continuous Injection Moulding (ACIM) is a highly advanced process for manufacturing Silicone Rubber composite insulators. This process (Fig. 24) is a further development of PFISTERER's pioneering work in this field, which combines the extensive experience in high pressure multiple injection moulding with the outstanding service records of the preferred HTV-Silicone Rubber system. As an additional benefit to users, the insulator geometry is practically unlimited. The feature of a turned mould line – known to improve the performance of moulded insulators – has been implemented as well. When introducing this innovation, special care has been taken to consider today's special requirements such as high creepage demands, compact solutions or DC applications.

From a technical point of view, ACIM offers a flexible production process and enables proven and "globally renowned" manufacturing processes and materials to be used. This means, no compromise at all in technical performance with the advantage of bulk volume production costs.

Fig. 24: ACIM production line

Sealing - Main Principles Process

Years of experience have resulted in "casting" (Fig. 25) and "overmoulding" or "overcasting" (Fig. 26) being the main principles of sealing systems. They are used today for the insulator housing manufacture in RTV/LSR-low pressure cavity casting, in the HTV-injection moulding process and in the HTV-modular process.

The two main principles of sealing systems operate to a reliable level when certain design rules are respected (including corona-free insulator string design). If the insulator housing is sealed by means of overmoulding or overcasting, an adhesive bond by means of a primer is used to bond the housing material stable with the fitting. The "chemistry" for this type of sealing is more challenging than for casting because the composition of the zinc layer on the steel fitting essentially determines the adhesion strength. HTV injection moulding is beneficial here because, empirically, it has been established that a higher process pressure leads to better adhesion and a greater fault tolerance than low pressure cavity casting. In accordance with the relevant standards, proof of a safe design is furnished by means of the interface tests applicable.

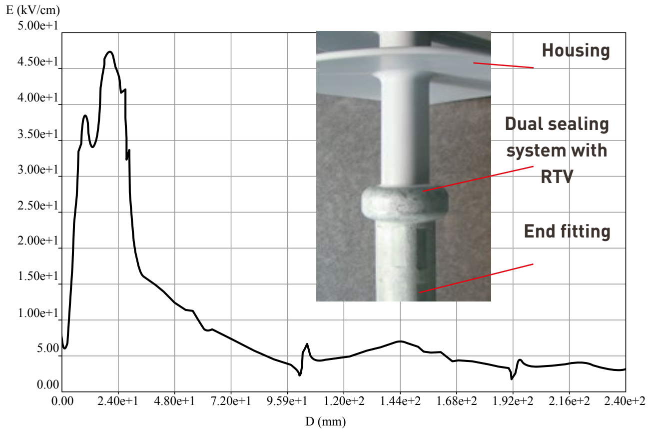


Fig. 25: Sealing by casting with E-field simulation

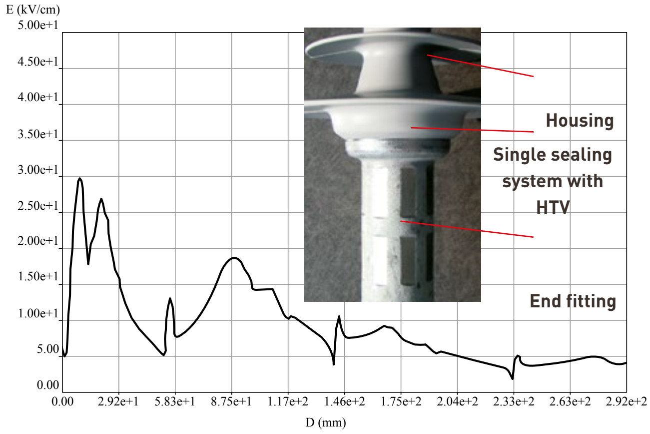


Fig. 26: Sealing by overmoulding with E-field simulation

Sealing - Corona Shed as an innovative Solution Process

Is it well proven that a higher field stress can occur with casting than with overmoulding. This is due to the non-embedded fitting at the triple junction. Simultaneously, the used materials for sealing have a low erosion and tracking resistance due to the required elasticity. This combination is unfavourable under certain outdoor conditions and for inappropriate insulator set designs. Also, there is the risk of handling damages. To solve this situation for insulator designs, which cannot be overmoulded, a patented corona shed solution was established, which employs the combined experiences of casting and overmoulding:

- The primary sealing system (silicone gel) proven since decades is retained,
- Embedded fitting reduces the electrical field stress,
- The conical shape also results in a lower field stress in the first shank area,
- The sensitive yet service-relevant sealing interface is protected by HTV-silicone rubber, which consists of high-ageing resistant,
- The shank and fitting are sealed using a form-fit and adhesive bond that will ensure the long-term protection of the primary sealing system.

PFISTERER recommends either the use of the corona shed or sealing by overmoulding for voltage classes ≥ 170 kV.

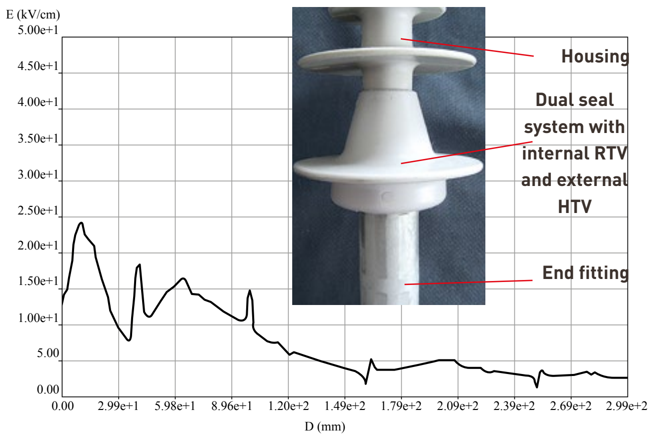


Fig. 27: Sealing by corona shed with E-field simulation

Testing Process

Applicable product standards such as IEC 61109 require sample and routine testing for the product lots.

For the sample testing, the following sample sizes are specified as shown in table 3:

Lot Size N	Sample Size
⩽ 300	to be agreed
300 < N ⩽ 2,000	4
2,000 < N ⩽ 5,000	8
5,000 < N ⩽ 10,000	12

Table 3: Sample size as per IEC 61109

Fig. 28: Tensile machine

For routine testing, a typical range of 50 – 80 % of SML is established.

For tensile testing, PFISTERER uses fully automated machines (Fig. 28), the results are digitally recorded and saved for ten years.

In addition to the standard test requirements, the following tests are carried out strictly according to internal work processes:

- Ultimate tensile testing for transition of batches of end fittings or rods,
- Adhesion testing (Fig. 29),
- Interface testing by boiling,
- Visual hydrophobicity check.

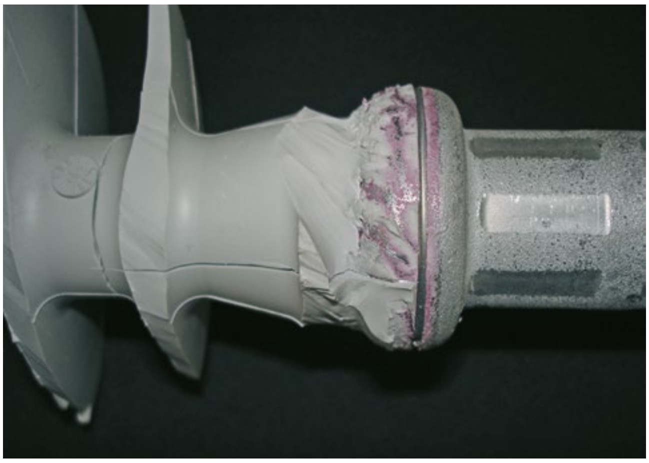


Fig. 29: Adhesion testing

These additional routine tests guarantee the required quality for a bulk volume manufacturing.

In some cases, e.g. for life line work and corresponding insulator replacement under service voltage or for life-line sticks, an electrical routine test might be required.

Typically, this test is performed at line-to-ground or elevated line-to ground voltage and evaluates the insulators for hidden electrical defects.

This test can easily be performed in PFISTERER's HV laboratory, situated close to the factory (Fig. 30).

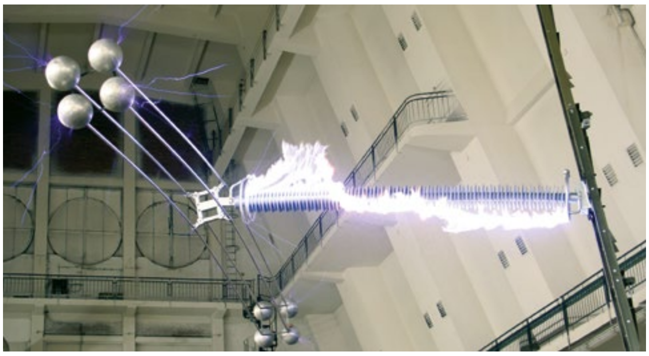


Fig. 30: HV-testing as special demand

Handling and cleaning

Preface

The following recommendations for insulator handling were created on consideration of the work performed in CIGRE Working Group B2.03 and the published Technical Brochure 184. The recommendations are divided into handling and cleaning.

Handling

Despite of the overall advantages of composite insulators, they are not indestructible. On their way from the manufacturer to the final position on the tower, the insulators go through different stages: receipt and storage, transportation, on-site handling, installation on tower/pole and conductor stringing. These stages require a certain amount of care to be taken.

Damage or a penetration of the housing would reduce the creepage distance or expose the rod. Both can reduce the insulation behaviour or the lifetime of the insulator. Such situations can occur when knives are used to unwrap insulators (Fig. 31) or nails are exposed in the wooden packing box.

Insulators should be transported in their original crate with the lid in place. When the insulators are removed from the box, they must never be transported loosely or with other material on top (Fig. 32).

Fig. 31: Avoid cutting of housing

Fig. 32: Prevent transportation damage

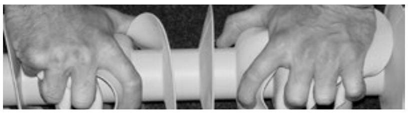


Fig. 33: Avoid excessive bending or torsion

Fig. 34: Climbing on insulators is prohibited

Fig. 35: Prevent direct contact of the rope and the housing

The unidirectional reinforcing glass fibres in the rod provide the excellent axial tensile strength. This reinforcement is not designed for torsion. For this reason, no torsional or bending load must be applied to longrod insulators (Fig. 33).

Climbing along, sitting or crawling on insulator sets is not permitted (Fig. 34).

Although the mechanical strength of the rod inside the insulator could easily bear a man's weight, it is prohibited to do so to prevent damage to the housing. Aluminium ladders are often used as an alternative.

When ropes are used to lift the insulator, the ropes should not be thrown over the housing (Fig. 35), but must instead be fixed on the end fittings.

Cleaning

The hydrophobicity is an essential value-added property of composite insulators with Silicone Rubber housing. This property includes recovery after exposure to moisture and the transfer of hydrophobic properties into a pollution layer by the diffusion of low molecular weight polymer chains from the bulk material. This unique property of a well-formulated Silicone Rubber keeps the water-repellent properties in service. As a result, cleaning is generally not necessary.

Very seldom, there are cases of special pollution, which might require the housing to be cleaned. Such reported cases are extreme axial pollution by large birds or mould growth. Mould growth is often attributed to inappropriate storage in a non-ventilated atmosphere leading to condensation on the housing. Acetone, Toluol, Trichlorethylene or Isopropanol are typical solvents for cleaning. The cleaning agent should be applied to a lint-free cloth with which the surface of the insulator should be wiped.

WARNING

- Cleaning agents should be used in wellventilated areas and should not be inhaled.
- Avoid contact with the skin.
- In the case of volatile fluids, do not use naked flames.
- Data sheets and National Laws must be followed.

Diagnostics

Preface

There is a relatively wide variety of insulator designs, involving different manufacturing processes (e.g. housing bonded and not bonded to the rods, crimping pattern), various design rules (e.g. rod diameter for a certain tensile load) and concerning the materials used (e.g. rod composition, housing materials). Some composite insulators have been successfully in service for thirty years; however the variety means that diagnostic techniques should ideally be applied, preferably enabling inspection in service.

Diagnostic Principles

Diagnostic Techniques		
Off Line (Laboratory)		Live Line
Repetition of IEC Test Methods used for Materials and Design Qualification	Specific Testing	
IEC 61109	Hot Stick Tester*	E-Field Measurement***
IEC 62217	PD* / RIV**	UV Measurement (Night and Day Vision)
IEC 60587	Heat+Voltage*	Line Inspection (Visual)
	Infrared Measurement	Infrared Measurement
	UV Measurement (typically Night Vision)	Combined UV- and IR Measurement
	E-Field Measurement***	
	Visual	
	Direct Acoustic Detection****	

Table 4: Applied diagnostic principles

* Insulators with imminent risk of failure
** If no other RIV sources than the defect exist
*** Requires high conductive defects
**** Requires high PD level (> 40 pC)

From these Diagnostic Techniques, the Visual Inspection, E-Field Measurement and UV/IR Measurements are discussed more in detail.

Line Inspection

Visual line inspection was the first method and is still the method most commonly applied by utilities. Typically, surface damages can be identified, which could be an indicator for internal defects. The defects are often small in appearance, requiring very powerful binoculars. Visual line inspection needs both an experienced helicopter pilot and an experienced line inspector (Fig. 36). Obviously, the upper side of tension string insulators can be visually investigated, which is rather difficult from the ground. Solution with drones are under development.

Fig. 36: Helicopter inspection

Field Measurement

Measuring with a field probe (Fig. 37) is an accurate, but time consuming method. Initially, this technique was developed for the in-service evaluation of cap and pin insulator strings. With the increased service time of composite insulators, the field probe has subsequently been modified to also evaluate the new insulator technology. In principle, measuring involves mapping of the electrical field along the insulator. If a defect is found, the electrical field will show an immediate change. The ambient humidity has a strong influence on the field recordings, which makes interpreting the results difficult at such times.

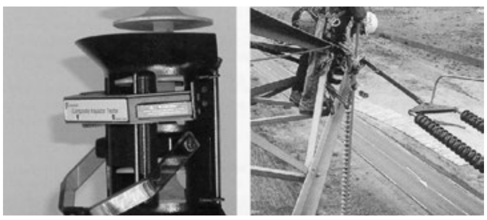


Fig. 37: Field probe measurements

UV/IR Measurement

Advances in the optical and electronic industries have produced the next generation of cameras which can simultaneously provide ultraviolet, infrared and normal images of electrical equipment, including insulator strings and apparatuses.

Corona activities can be measured in daylight (Fig. 38) or hot spots can be detected. The images can be superimposed (Fig. 39), which simplifies the interpretation of the results.

However, this interpretation requires experience too. For example, it is important that the various types of electrical discharges occurring on an insulator are differentiated. Dry band discharges have an UV radiation as well, but are mainly caused by pollution on the insulating surface. On the other hand, (dry) corona discharge is initiated at areas of high electric field stress caused by sharp or irregular points on metallic or insulating surfaces. Since the corona discharge is formed by the partial breakdown of air, it is important to record the prevailing weather conditions simultaneously with the measurement. It has been empirically proven that observations/measurements are required during periods of both high and low humidity before any conclusions on the corona performance of a particular insulator or an insulator set can be drawn.

Measurement of temperature enhancement provides a great deal of information also in stations and for current-carrying contacts.

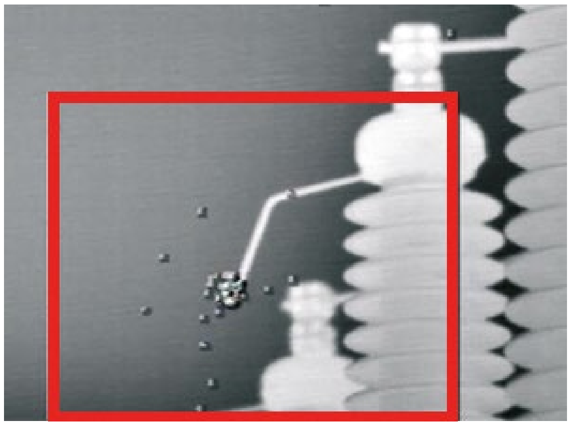


Fig. 38: Corona activity can be measured in daylight

Fig. 39: Superimposed image of IR and corona measurement of the same bushing

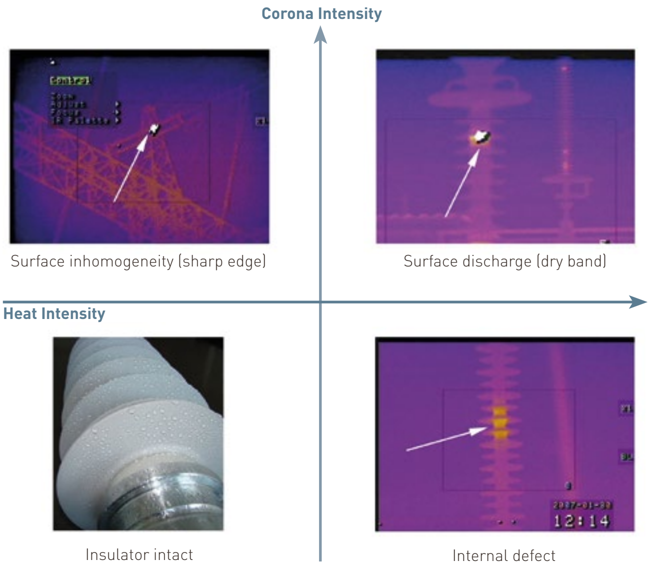


Fig. 40: Proposal for a failure interpretation matrix (photos courtesy of CSIR)

CIGRE WG B2.21 has published the Technical Brochure 545 in 2013, entitled "Assessment of in-service Composite Insulators by using Diagnostic Tools" as an update of the state-of-the-art of line component including insulator diagnostic. An example, when using both UV and IR diagnostic is shown in Fig. 40.

The currently available results of measurements on insulators with artificial and real defects have clearly shown that the modern camera systems assist the inspection in a supplementary way; the correct interpretation of the images still requires a skilled line inspector.

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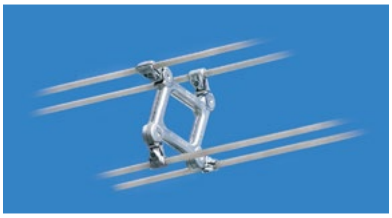
PFISTERER's Centre of Competence for Overhead Lines

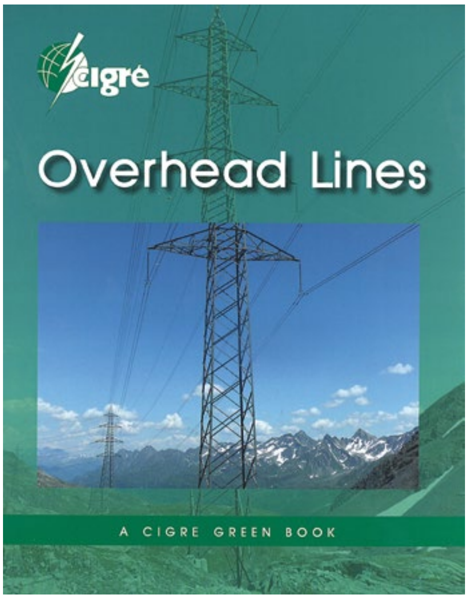
INSULATOR SETS

COMPOSITE INSULATORS



VIBRATION CONTROL

AUTHORED OR CO-AUTHORED REFERENCE BOOKS



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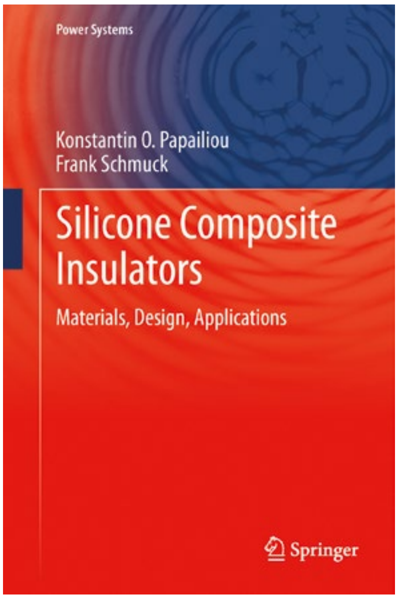

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