HIGH VOLTAGE INSULATORS

By JP Holtzhausen

The principal dielectric used on overhead power lines is air at atmospheric pressure. The air, surrounding the bare high voltage aluminium or steel- cored aluminium (ACSR) conductors, is a good insulating material, provided that the electric stress is kept below the ionisation threshold. It is, however, necessary to attach the conductors at certain points onto the cross arms of the pylons. The problem of reliably suspending the conductors of high voltage transmission lines has therefore been with us since the turn of the century. The task is particularly complex, bearing in mind the multiple extreme stresses present: mechanical, electrical and environmental.

ELECTRICAL

High voltage insulators have developed rapidly since early this century, beginning with simple porcelain insulators (I). Today, modern polymeric insulators are used, as well as the earlier materials. A classification of the main types of insulators is shown schematically in *figure 1*.

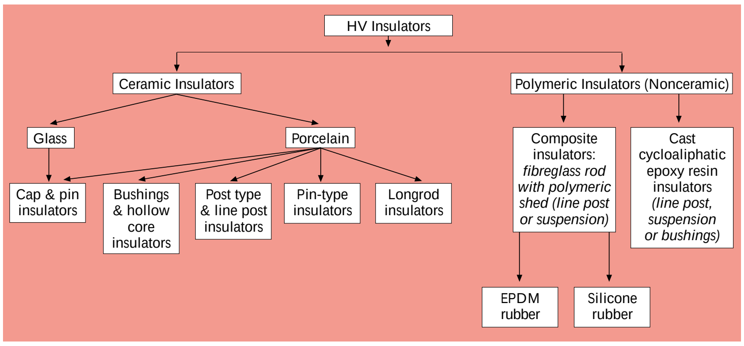
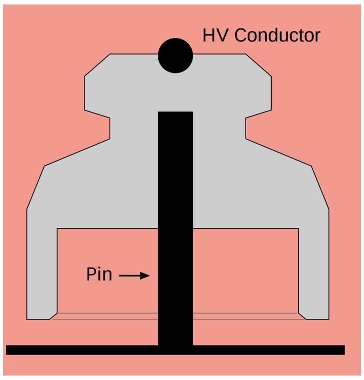


Figure 1
The classification of power line insulators



Porcelain pin type insulators

These were originally used for telephone lines and lightning conductors, have been adapted for power transmission and some variations are still in use for medium voltage systems. A pin-type insulator is shown schematically in *figure 2*.

Figure 2
Schematic representation of a section through a pin-type insulator

Cap and pin insulators

These are manufactured from porcelain or glass and are based on the same principles as pin-type insulators. A number of units are connected together by steel caps and pins to form an insulator string. These strings are used for suspension and tension insulators. The caps and pins are fixed to the glass or porcelain disc with cement. The conical shapes of the fittings ensure high mechanical strength under tensile stress. Typically an insulator string can handle loads of up to 120 kN, i.e. 12 tons. A typical cap and pin disc is shown in *figure 3*. Pin-type and cap and pin insulators are classified as Class B insulators; the shortest distance between the metal electrodes through the porcelain or glass is less than 50% of the shortest distance through the electrodes. The porcelain or glass can therefore be punctured by severe electrical stress. The manufacturing process of glass insulators includes thermal cooling that ensures that the glass sheds shatters in the event of a puncture. A faulty disc is therefore clearly visible. The mechanical integrity of the insulator remains intact.

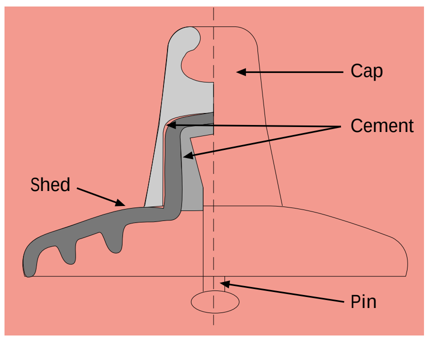


Figure 3
Typical cap and pin disc

Post-type and line post insulators

These insulators consist of a solid porcelain cylinder, corrugated to increase the leak- age length, with metalware on each end. They are used to support the high voltage conductor and are mounted on pedestals or on the power line cross arms. Post insulators are tall and are mainly used in substations. These insulators are Class A; the shortest distance through the porcelain exceeds 50% of the shortest distance through air between the electrodes. They are therefore unpuncturable. A typical example of a post insulator is shown schematically in *figure 4*.

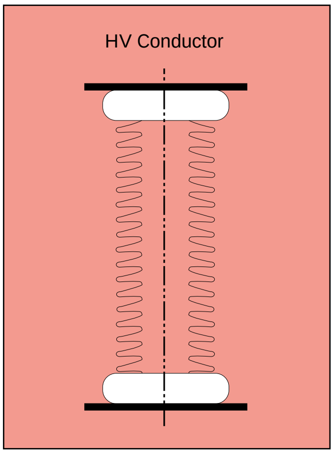


Figure 4
Typical post-type insulator

Porcelain longrod insulators

Longrod insulators are similar to post insulators but are lighter, slimmer and are used as suspension insulators. Longrod insulators have the apparent advantage over cap and pin insulators in that metal fittings exist only at the ends of the insulators.

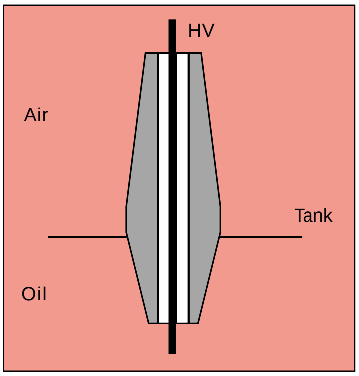


Figure 5
Typical post-type insulator

Bushings

Bushings are used to insulate the conductors of the high voltage ter- minals of a transformer as is shown schematically in *figure 5*. Traditionally, transformer bushings are manufactured using porcelain. Capacative grading, using foil cylinders is often used to improve the axial and radial field distribution.

Composite polymeric insulators

These insulators are similar to longrod insulators but consist of:

- A glass fibre reinforced resin core to provide the mechanical strength, while resisting the electrical stress
- Elastomer sheds to provide the required creepage and stress reduction to withstand the stresses prevailing on the system. Two commonly used materials are silicone rubber and EDPM (ethylene propylene diene monomer) rubber.

A typical method of construction is shown schematically in *figure 6*. The metal end fittings are usually crimped onto the glass fibre rod from the environment and the interfaces between the elastomer and the metal fittings are very important. Tests to ensure the quality of composite insulators are contained in IEC 1109 [2].

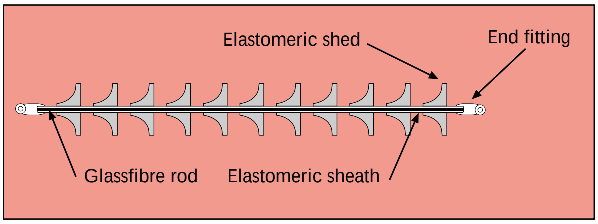


Figure 6
A schematic representation of a typical polymeric composite insulator

A major advantage of composite polymeric insulators is an up to 90% weight reduction when compared to ceramic equivalents. They are also reasonably vandal-proof.

Cyclo-aliphatic epoxy resin insulators

Cyclo-aliphatic resin can be used to cast insulators similar to porcelain and linepost insulators for distribution voltages. In severe environments the surfaces of the insulators become rough - a factor that may affect the reliability of the insulator, when incorrectly applied.

Terminology

When applying insulators, it is necessary to describe the insulator dimensions, using the following terms:

- Creepage distance: the shortest distance between the metalware at the two ends of the insulator, when following the contours of the insulator, excluding intermediate metal fittings. This distance is easily measured by sticking masking tape to the insulator surface.
- Specific creepage distance: The quotient of the creepage distance in mm and the line-to-line rms. voltage of the three phase system in kV
- Connecting length: the axial length of the insulator between the end terminals
- Arcing distance: the distance between the metalware, measured as the length of a tightly pulled piece of string
- Intershed spacing: the distance between corresponding points on adjacent sheds.

Pollution deposition process

Insulators exposed to the environment collect pollutants from various sources. Pollutants that become conducting when moistened are of particular concern. Two major sources are considered:

- Coastal pollution: the salt spray from the sea or wind-driven salt laden solid material such as sand collects on the insulator surface. These layers become conducting during periods of high humidity and fog. Sodium chloride is the main constituent of this type of pollution.
- Industrial pollution: substations and power lines near industrial complexes are subject to the stack emissions from nearby plants. These materials are usually dry when deposited; they may then become conducting when wetted. The materials will absorb moisture to different degrees, and apart from salts, acids are also deposited on the insulator.

The role of the weather

Wind is instrumental in the deposition process. High humidity, fog or light rain cause wetting of the pollution layers. Heavy rain removes the pollution layer especially on the upper sides of the sheds.

Air flashover versus pollution flashover

If the electric stress in air at atmospheric pressure exceeds 3 kV/mm, ionisation can occur. Depending on the gap configuration, flashover may follow. The power flashover voltage of a clean dry single cap and pin insulator with a 280 mm creepage distance is 72 kV. It is estimated that using a 15 mm per kV specific creepage distance under medium pollution conditions will cause a flashover at 3.67 kV - an almost tenfold reduction in performance. This dramatic reduction in flashover voltage is attributed to the presence of the conducting layer on the surface of the insulator. Leakage current flows over the insulator surface and the heating effect of the current causes drying out of the layer at certain spots and the formation of 'dry bands'. Arcs occur across these bands and if the pollution is of sufficient severity, the insulator may flash over [1].

Hydrophilic versus hydrophobic insulators

As indicated above, the presence of a conducting layer on the surface of an insulator is essential for pollution flashover to take place. In particular, sufficient wetting of the dry salts on the insulator surface is required to form a conducting electrolyte. The ability of a surface to become wet is described by its hydrophobicity. Ceramic materials and some polymeric materials such as EDPM rubber are hydrophilic, i.e. water films out easily on its surface. In the case of some shed material such as silicone rubber, water forms beads on the surface due to the high surface energy.

When new, the hydrophobic properties of silicone rubber are excellent; however, it is known that severe environmental and electrical stressing may destroy this hydrophobicity. Silicone rubber materials also have the property that, once lost hydrophobicity can be regained after a 'resting period'. These aspects are being researched in several countries.

Failure modes of insulators

Flashovers, caused by air breakdown or pollution, generally do not cause physical damage to the insulators and the system can often be restored by means of autoclosing. Some other events, however, cause irreparable damage to the insulators.

Puncture

As previously mentioned, porcelain pin-type and cap and pin insulators may suffer punctures between the pin and the either the pin or the high voltage conductor. These occurrences are usually caused by very steep impulse voltages, where the time delay for air flashover exceeds that of puncture of porcelain.

Punctures caused by severe stress over dry bands also occur on composite insulators on sheds and through the sheath. A puncture of the sheath is particularly serious as this exposes the glass fibre rod to the environment (see brittle fracture below).

Shattering

Glass insulators shatter when exposed to severe arcing or puncturing due to vandalism. One advantage is that they retain their mechanical integrity.

Erosion

Prolonged arcing of glass insulators leads to erosion of the surface layer of the glass. This may lead to shattering of the glass discs - a result of the tempering process used during manufacture. Arcing and corona over long periods may cause removal of shed or sheath material in the case of polymeric insulators. Severe erosion may lead to the exposure of the glass fibre core (see brittle fracture)

Tracking

Tracking occurs when carbonised tracks form because of arcing. These tracks are conductive. This phenomenon only occurs in carbon-based polymers.

Brittle fracture

Water entry into the glass fibre core of composite insulators, coupled with the influence of weak acids, has been shown to lead to brittle fracture of the rod. The by-products of partial discharges in the presence of water can lead to the formation of weak acids. The integrity of the metal/polymer and glass/polymer interfaces is therefore extremely important - especially if acid-resistant glass is not used.

Corrosion

The corrosion of metal fittings clearly affects the mechanical performance and lifetime of insulators. The corrosion products, running onto the insulator sheds can also initiate deterioration.

Remedies

Washing

Substation or line insulators can be washed when de-energised or when energised. Automatic washing schemes and helicopters have been used for this purpose. The costs are usually prohibitive.

Greasing

A thin layer of silicone grease, when applied to ceramic insulators increases the hydrophobicity of the surface. Pollution particles that are deposited on the insulator surface are also encapsulated by the grease and protected from moisture.

The disadvantage of greasing is that the spent grease must be removed and new grease applied, usually annually.

Coatings

Room temperature cured silicone rubber coatings are available to be used on ceramic substation insulators. These coatings have good hydrophobic properties when new. Research is still in progress to evaluate their aging processes.

Increase creepage distance

If the clearances allow, additional discs may be added to increase the reliability of a line. In the case of longrod and post insulators, the increased creepage length must not result in an inadequate shed spacing. This solution is usually not possible and expensive.

Replace hydrophilic with hydrophobic insulators

One possibility may be to replace hydrophilic with hydrophobic insulation of the same connecting length and creepage distance. This solution is, however, expensive and it must be known with certainty that the original problem is pollution related.

Application guide

The design of a new line and the choice of insulators is a specialised task. Apart from the coordination of the line insulation to cope with lightning and switching impulses, the pollution severity of the area must be known - through either direct measurement or experience. Recommendations by the IEC indicate design criteria for ceramic insulators [3].

Choice of creepage length

The recommended specific creepage lengths for ceramic insulators are given in *table 1*.

Site pollution severity	Low	Medium	High	Very high
Specific creepage length (mm/kV)	16	20	25	>31

Table 1

When using non-ceramic insulators, it is advisable to use a shorter creepage length, especially in locations of severe pollution. Recent research indicates that under conditions of severe humidity and dry band arcing, silicone rubber insulators may lose hydrophobicity. Until more conclusive research results or revised specifications are available, it is considered a safe approach to use IEC 815 for non-ceramic insulators as well.

Choice of profile

Suitable spacing and shed overhang/spacing ratios have to be chosen [3]. A long creepage distance, obtained by using many closely spaced sheds may be inadequate as intershed breakdowns can occur.

Choice of shed material

Hydrophobic materials are preferred for areas near sources of pollution.

Conclusion

During the earlier part of this century ceramics, glass and porcelain have been established as reliable materials for high voltage insulation. Over the past few decades, new technologies involving polymeric materials have increasingly been used for transmission and distribution systems. These insulators have many advantages over other materials.

References

[1] Looms, J. S. T., "Insulators for High Voltages". Peter Peregrinus, London, 1988.

[2] IEC 1109: 1992. "Composite Insulators For AC Overhead Lines With Nominal Voltages Larger Than 1000 V - Annexure C".

[3] IEC 815. "Guide for the Selection of Insulators in Respect Of Polluted Conditions". IEC Recommendations. Publication 815, 1986.

[4] Vosloo, W. L., Holtzhausen J. P., Roediger A. H. A. "Leakage Current Performance of Naturally Aged Non-ceramic Insulators Under a Severe Marine Environment". Africon, September 1996, Stellenbosch, 1996.

[5] Holtzhausen J. P. "Leakage Current Monitoring On Synthetic Insulators at a Severe Coastal Site". The Transactions of the South African Institute of Electrical Engineers. September 1994.