PPC INSULATORS

Optimized Insulators for Different Environments and Applications

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What is an Insulator?

A HV Insulator is a tool that normally doesn't do the insulation work, except for Pin types and some Hollows, but instead is a mechanical device that maintains a distance between two electrically conducting parts that have different voltage levels. A fundamental demand is that the Insulator itself does not conduct electrons. This is a minor problem; the main areas of complications are:

1) The air surrounding the Insulator normally has a lower electrical strength than the insulator itself.
2) The interface between the Insulator and the surrounding air can reach a high level of electrical conductivity. The resulting current can create increased concentration of ions in the air close to the Insulator interface, which decreases the electrical strength of the surrounding environment.

How does an Insulator perform its duty?

Mechanical

The basic demands regarding mechanical forces are:

- That the Insulator is strong enough - i.e. does not break with the applied load, and
- That the Insulator is stiff enough - i.e. does not allow the conducting parts to change position with relation to each other by more than a specific limit.

An insulator is exposed to different types of Mechanical load:

1) Bending load. Post insulators are a typical example of how bending forces determine the mechanical design strength. The bending load will also result in a bending of the Insulator. The amount of bending is determined by the bending force, design of the Insulator and the stiffness of the material from with the Insulator is made. The stiffer the material, the less "over design" is needed for long Insulators.

2) Tensile load. Cap & Pin and Long Rod are typical examples of Insulators working under tensile load. The main demands in this case are to use a design giving a sufficient strength, using a material with long term stability of the tensile strength - i.e. no or extremely slow ageing and re-crystallization
3) Torsion loads. Torsion Rods are Insulators that operate with torsion forces. Other Insulators might also be exposed to torsion forces during use or installation. In principal, an Insulator must have a minimum core diameter, depending on material, to survive the torsion forces.
4) Compressive Load. Normally, an Insulator is not designed for a specific compressive force; in most cases other forces determine the design. One exception is the Post Insulator for Subway current suppliers in some countries, where high compressive forces are produced when a train is passing.

Designing an Insulator to meet mechanical demands is the least complicated task when producing an optimized product. The key is to devise a design using the optimum shape and materials in such a way that the needed material properties are maintained for a long time, normally >50 years.

Electrical

As indicated initially, current can pass by three different ways between two different conductors, with different voltage levels, that are spaced by an Insulator:

1) Through the Insulator material. This normally happens only with Pin type Insulators. The reasons behind such a failure include:

   - Cracking of the insulating material, which may be the result of either development of communicating micro cracks in the material normally coming from re-crystallization of remaining Quartz, or a total sudden cracking of the insulating body by release of inherent forces. Both of these events result in a Puncture.
   - The ionic conductivity that can develop under DC Voltage, especially at elevated temperatures, in materials with insufficient properties.

   The main ways to prevent such negative effects are to select appropriate materials, and perform 100% Puncture Testing during production.

2) Through the air around the Insulator, Flash Over.

The environment has limited influence on the insulative strength of air surrounding an Insulator; even high levels of aerosols or particles in the air have limited influence and can even increase the electrical strength. The main influences on the insulative strength of the surrounding air are from the atmospheric pressure, and from ions produced at the conductors ends. Typically, the most important source is the current passing on the interface of the Insulator, if it is covered with an uneven conducting contamination layer. The conducting contamination layer on the interface is normally not homogenous and continuous from end to end. The small interruptions are bridged by micro flashing which produce ions that diffuse out towards the surrounding air. If the conductivity of the air becomes too high, an avalanche process with longer and longer flashes will start, including streamers, which can end with a total Flash Over.

3) Through a contaminating layer on the interface between the surrounding air and the Insulator.

The main base for Insulator Technology is how to, in an operative and economical way, best handle the problems with conducting contamination layers that build up on the interface of an Insulator. The leakage current results from the areas with contamination covering a sufficient part of the interface of an insulator. If the contamination layer is covering the total interface evenly, there is normally not a problem; if the conductivity is below a specific limit, it is actually the property of the Semi Conducting Insulator that has superior performance! The problem with leakage current materializes when a part of the interface is covered with a conducting layer and the remaining part has a high insulation level on the interface. If the insulating part of the distance is short enough, the current will pass these areas as sparks. The sparks produce ions that decrease the electrical strength of the air, which can cause an avalanche ending with a Flash Over.

What issues affect Insulator performance?

The parameters influencing the level of leakage current, and especially the resulting micro arcing are the environment, the properties of the interface and the shape of the interface.

Environment

The tailoring of the environment is not a part of the Insulator Technology.

Interface Properties

We have today principally two different types of interfaces on Insulators:

Organic Hydrophobic

1) The silicones, the most common hydrophobicity generating material, with high filler content, here named HFS.
HFS is used for creating the outer shape of the Insulator, normally by high temperature curing of a semi liquid material in a mold. The interface of HFS is hydrophobic below a specific humidity level, but above this level the hydrophobicity disappears. After loss of hydrophobicity the recovery, by diffusion of new silicon molecules to the hydrophilic surface, takes some time, which is influenced by the filler content and the molecular weight of the silicon. HFS does also have a relatively high thermal conductivity.

2) The more pure silicones with lower molecular weight; an example is RTV.
RTV is normally used as a coating on an Inorganic Insulator body and can be applied on already installed Insulators. The main difference in performance, compared with the HFS, is the lower thermal conductivity and higher resistance against humidity in the surrounding air before the hydrophobicity is lost, and the quicker recovery of hydrophobicity after such a loss. The lower thermal conductivity of RTV results in a lower formation of dew on the interface in the mornings.

In summary

HFS & RTV have good interface properties if the humidity is kept below a certain, material specific level. The level is higher for RTV than for HFS, and RTV has a quicker recovery of hydrophobicity after a loss. The lower thermal conductivity of RTV also gives higher resistance against morning dew. Both of these materials do age and the interface properties degrade with time, but up to date materials seem to have an acceptable lifetime of the interface properties.

Inorganic Glass and Glaze

All types of Inorganic Insulators do in principal have the same type of interface, but the quality is different between different producers. Such an interface is initially hydrophobic but this quality is lost permanently within a short time, weeks. After the loss of hydrophobicity, the interface properties are unchanged throughout the life time of the Insulator, independent of the environment, and keep a high level of inertness and self cleaning properties.

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In summary

Organic interfaces have advantages in some environments where low humidity is present at least part of the time, to maintain a stable hydrophobicity or at least regularly create a recovery. Disadvantages include less good properties after loss of hydrophobicity; therefore, the use of such material must be very much based on environmental factors. In addition, ageing can also be a factor if very long time performance is of high priority and the environment is severe.

Inorganic interfaces have an advantage in that the properties are very much independent of the environment and time, and the inertness makes the self-cleaning much more efficient.

Shape of the interface

The shape of the interface is a direct result of the shape of the Insulator. The basic demand on the interface is to:

1) Create as low conductivity as possible when covered with a conducting contamination layer.

   The conductivity of an evenly conducting surface is determined by the specific conductivity of the surface and the Form Factor [1] (FF). In reality the contamination layer is never evenly distributed or evenly conducting, but in general an Insulator with higher FF does also show lower creepage current over the interface.

   There are two ways to increase the FF of the interface of an Insulator, by

   a) Increasing the length of the Insulator interface that is parallel with the electrical field - i.e. the CD, and
   b) Decreasing the width of the Insulator interface - i.e. the diameter of the Insulator.

   The conclusion from the info above is that an Insulator should have as small diameter on all its parts as possible for fulfilling the mechanical demands and should at the same time have a sufficient length of the CD.

2) Minimize the ability for the contamination to cover the interface.

   By designing the sheds long, closer together and bent down, a protected CD/interface is generated. The more protection of the interface, the less amount of material will be agglomerated on the interface per time unit. The negative aspect of protected interface by this method is that the protection is also reducing the self-cleaning ability of the interface, and longer sheds are reducing the FF/CD relation.

3) Allowing optimum self cleaning performance by rain or wind.

In addition, the spacing between interface parts at different Creepage Distance (CD) from charged conductor must exceed a value specified in the IEC standards.

The self-cleaning capability is promoted by long distance between the sheds, short sheds and horizontal orientation of the shed angle.

Factors 2 and 3 above are pushing the designs in opposite directions; the design must therefore be related to the foreseen environment at the location where the Insulators will be installed.

Factor 1 is pushing the design towards longer/sufficient CD and smaller diameter. CD is a standard in present specifications of Insulators, but the mean diameter is normally not treated in the same way and should thereby be minimized for reaching optimum performance of the Insulator. An additional advantage with minimized mean diameter is that the weight is reduced, and for hollows the volume which must be filled with gas, oil or other material is also reduced, giving economical improvements for the total electrical system.

Conclusions

For a technically and economically optimized Electrical System, the Insulator design should be designed to fulfill all customer specifications and relevant standards, with an emphasis on:

- Minimized weight
- Maximized insulating/arcing distance
- Maximized FF
- Minimizing mean diameter possible with the material used
- Minimizing core diameter while fulfilling mechanical demands
- Maximizing mechanical strength and stiffness through optimized use of materials
- Tailoring the inside profile of hollows to correspond as closely as possible with the inside installed equipment
- Tailoring the shed profile, including fulfilling shed spacing demands, with minimized shed thickness, for the environment where the insulator will be installed

The following part of this publication will show examples of how we in PPC INSULATORS are fulfilling these basic rules.

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Methods of Design Improvements

Shed Design

The basic demands of shed design improvements include reduced weight and improved FF, while maintaining specified CD, relevant standards and customer specifications. The most direct way to fulfill these goals is to reduce the thickness of sheds. The pictures below show examples of traditional design and PPC´s advanced design with improved performance.

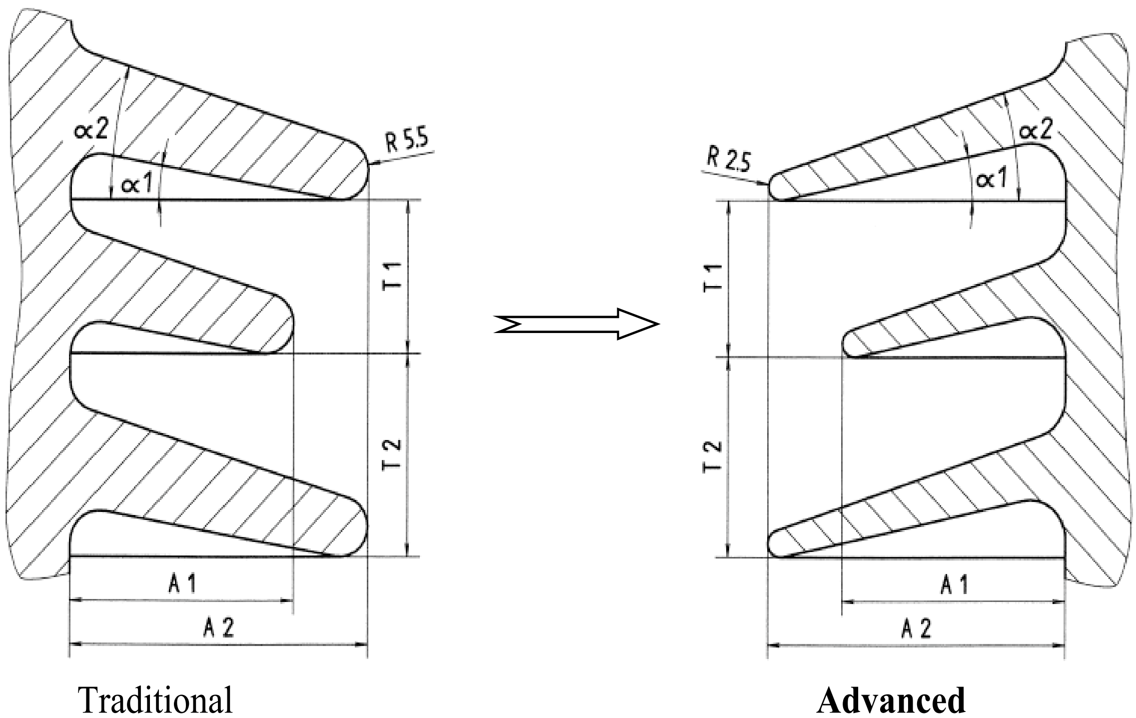


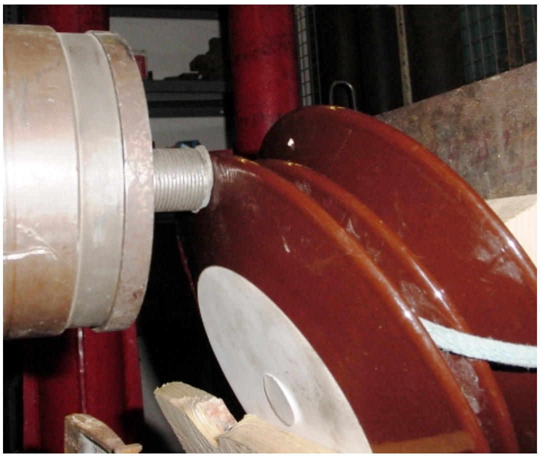
Fig. 1: Drawings of traditional and advanced shed design

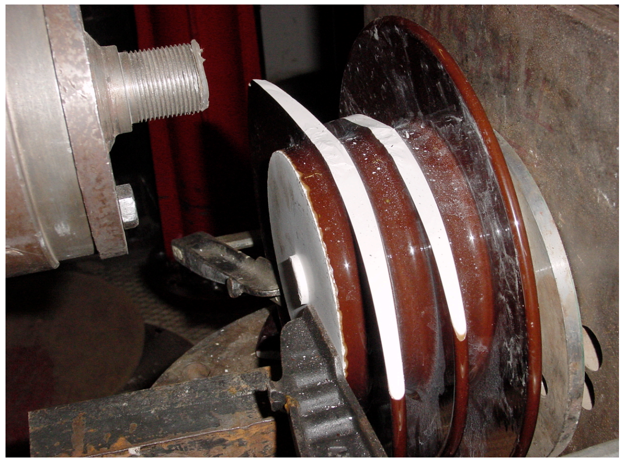
The result of this improved shed design is a weight decrease in the order of magnitude of 15 %. In addition FF will also increase with approximately 10 %.

The production of insulators with improved shed design demands advanced production technology. Such advanced technologies have been developed within the PPC companies during the last decades.

One early concern regarding this improvement was the mechanical strength of the sheds. Therefore, the development of the mechanical properties of the porcelain produced by PPC has been improved by higher basic strength and higher long term reliability. Detailed investigations have been made to confirm the relevant strength of the upgraded sheds.

One of the investigations was a mechanical strength test directly on the sheds, shown in photos 1 and 2 below.





Photos 1 and 2: Mechanical testing of advanced sheds

The results of the mechanical tests indicate a remaining relevant high strength of the sheds at a level well above the forces sheds are exposed to during handling and transportation. Unchanged internal handling within PPC plants, transportation and handling at customer sites confirm this - i.e. no damages on advanced sheds have been observed or reported.

InsuLite™

InsuLite is the trademark of products where several of the insulator improvements generated by PPC are combined. These improvements include advanced shed design and improved mechanical properties of the porcelain used. Photo 3 shows a post C9-1800 with CD 13750mm traditionally designed and an InsuLite design. Examples of improved characteristics of these two insulators are shown in table 1.

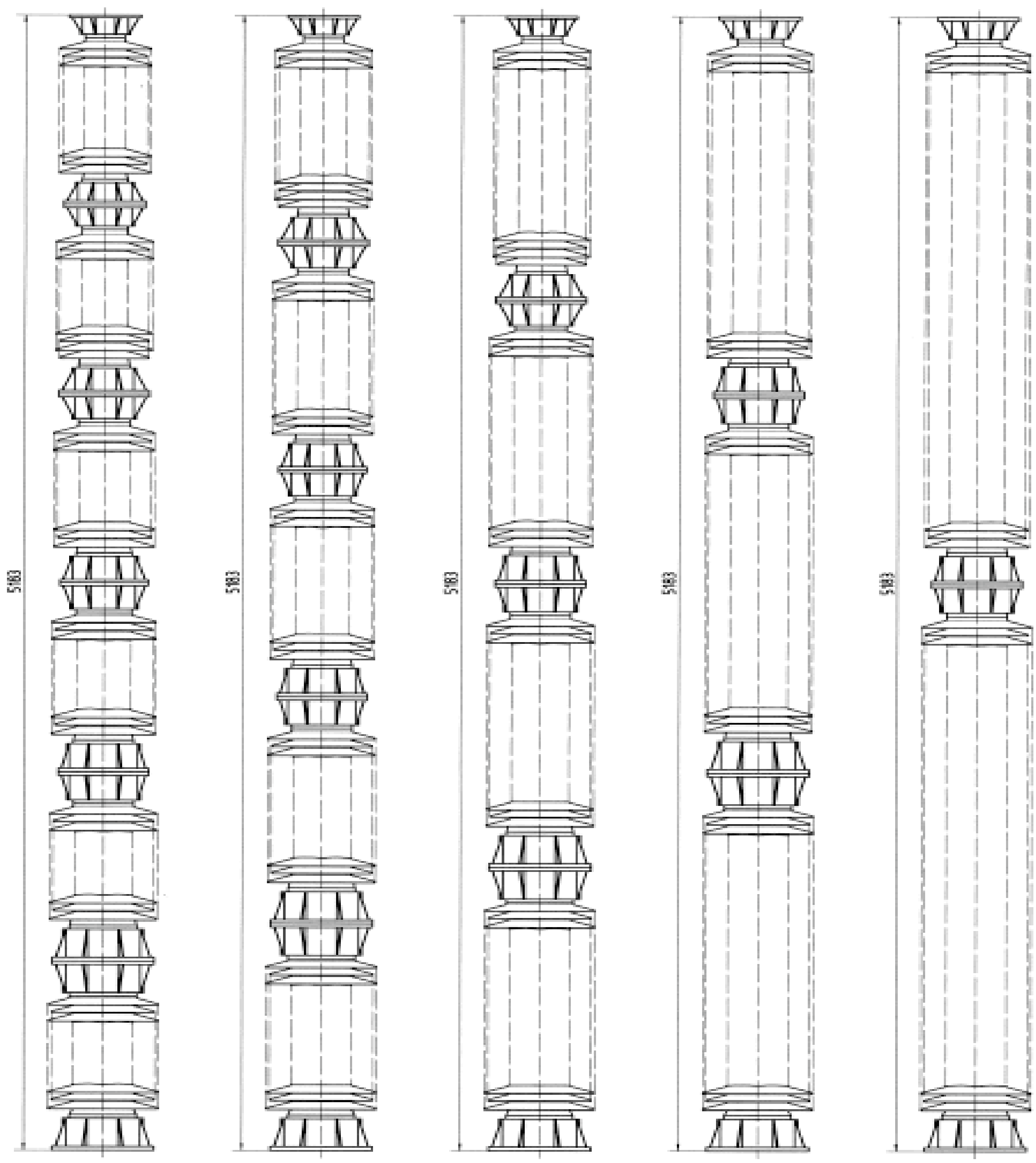
Table 1: Characteristics of post designs
- same basic material

C9-1800	Traditional	InsuLite
FF	17,532	23,002
Weight porcelain	451kg	365kg
CD	13750mm	
Mechanical strength	8kN	
BIL	1800KV	

Photo 3: Post C9-1800 with traditional- and InsuLite design

Advanced column Design

A large portion of tall post columns designed in the traditional way is made of metal. For an insulating concept, less amount of conducting material is an advantage. That is why one goal of PPC´s developments is to increase the length of the insulating sections of a column. As shown in Figure 2 the later development of a reduced number of insulating sections has been dramatic.



Traditional **Advanced**

Fig. 2: Drawings of traditional and advanced column designs for 800kVac application

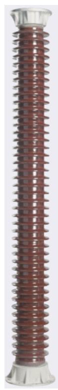
The column shown on the left side in Figure 2 is the traditional, earlier design, which is still used by some producers. In accordance with the developments of the technical level of electrical systems, more and more users are specifying their columns using a more advanced design, an example of which is shown in Figure 2..

The advantages of using the advanced design include longer arcing distance or shorter column height, improved FF, less weight, and lower costs for transportation and installation. PPC can provide the most advanced column designs available today.

Examples of Design Improvements and most advanced Designs

From 2 sections to 1 section (300kVac and below)

Traditional



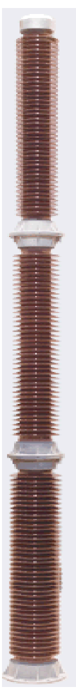
Advanced

Improved pollution performance

Weight reduction up to15 %

Improved arcing distance

From 3 sections to 2 sections (800kVac and below)



Traditional

Advanced

Improved pollution performance

Weight reduction up to 20%

Improved arcing distance

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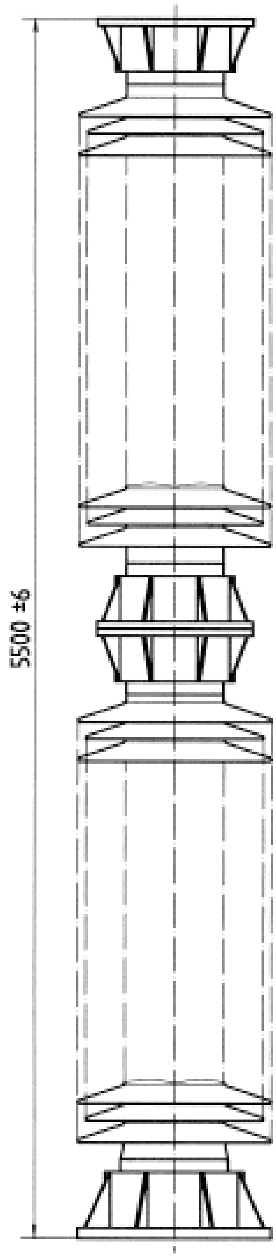
800kVac in 2 sections



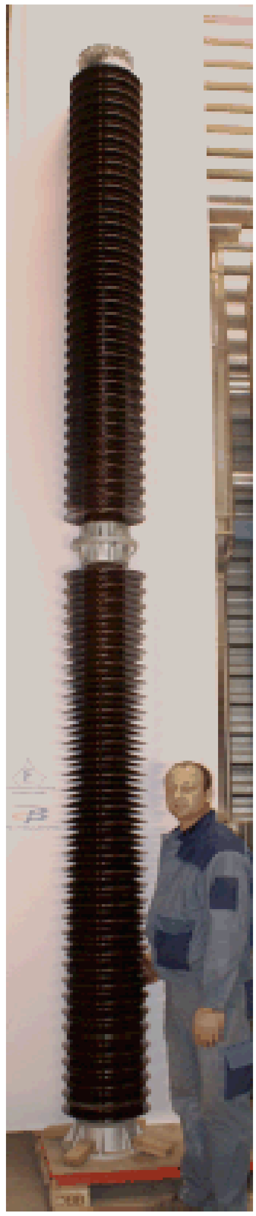


Photo 5: 800kVac
Column height 5,5m

Design Parameter: System voltage ………………………………. 800 kVac
Lightning impulse withstand voltage ………. 2550 kV
Switching impulse withstand voltage, wet …..1550 kV
Minimum failing load bending …………......... 8 kN
Minimum failing load torsion. …………….… 4 kNm
Minimum CD …………..………………….. 24800 mm

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800kVdc in 6 sections

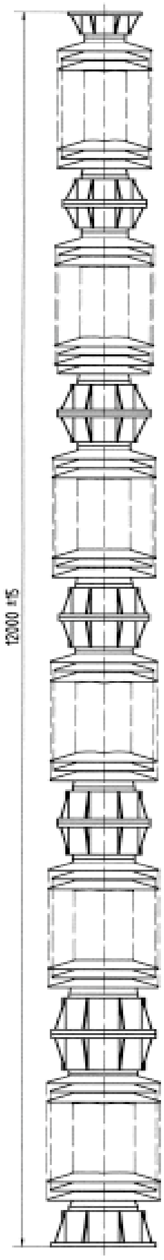

Photo 6: 800kVdc
Column height 12m -
in two 6m stacks

Design Parameter:

System voltage ……………………………….. 800 kVdc
Lightning impulse withstand voltage ……. .≥ 2550 kV
Switching impulse withstand voltage, wet... ≥ 1550 kV
Minimum failing load bending ………….........10 kN
Minimum failing load torsion. …………………. 4 kNm
Minimum CD …………..………………….. 49200 mm

Conclusions

All information given above is in general applicable for all types of insulators including hollows and solid core.

PPC has focused on being a leader in the development of advanced insulator designs and meeting the current demands of modern electrical systems. Priorities in such development include sustainability, long time reliable mechanical properties, electricity supply reliability and minimizing cost for electrical generation, transmission and distribution.

PPC strives to stay one step ahead in design advancements, keeping pace with modern system requirements and continuously providing our customers with the best technology available.

Reference

[1] IEC 60815