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# Application of dry-type high voltage condenser bushings for AC and DC transmission grids of the future

A. Doutrelepont, B. Heil
HSP Hochspannungsgeräte GmbH

## SUMMARY

High voltage conders bushings are a key component in AC and DC transmission grids while interconnection power transformers and shunt reactors to busbars and overhead lines. Insulating high voltage against earth and transmitting the respective currents bushings must be designed according to the applied electrical field, environmental stresses, and impacts such as pollution, flashovers, seismic events, and others. Since the beginning of the electrification era oil-impregnated paper (OIP) bushings have been widely applied and are still in operation as off today as they are known as matured technology. However due to safety reasons and environmental impacts nowadays dry-type epoxy resin-impregnated synthetic (RIS) bushings are the most advance selection of choice. Those dry-type condenser bushings housed with silicone rubber sheds offer many technical and commercial advantages such as:

i) Explosion-resistant due to no porcelain housing and no oil -> non-flammable
ii) No utilization of hazardous and environmental polluting materials and components,
such as mineral oil, $SF_6$ e.g.
iii) Higher currents and overload capabilities
iv) Suitable for a wide ambient temperature range: -60°C to +55°C
v) Seismic resistant

## KEYWORDS

Condenser bushing, resin-impregnated synthetic (RIS), sulphur hexafluoride ($SF_6$), carbon dioxide ($CO_2$), dissipation factor, partial discharge, hydrophobicity

## Introduction

Since many years different design and manufacturing methods for condenser graded bushings [1] are applied and available in the electrical power industry. While oil-impregnated paper (OIP) bushings are well known and used since decades in transmission and distribution grids in recent years dry-type epoxy resin-impregnated synthetic (RIS) bushings are becoming the selection of choice for system operators and utilities. OIP bushings are a matured technology which fulfils the technical standards and requirements however if it comes to in service performance OIP bushings may be exposed to several risks like the potential loss of insulation media, accelerating ageing of the paper insulation due to overheating and others. In such harsh in-service conditions RIS bushings can be adopted to minimize such risk and increase the safety of the respective transformers and reactors. In this paper the technological and physical advantages of RIS bushings will be elaborated and discussed.

## Principle structure and design of RIS condenser bushings

The main component of a high voltage condenser bushing is the so-called active part or condenser core which is in case of RIS a synthetic nonwoven as the carrier material for the epoxy resin material in which concentrically the aluminum layers for the individual capacitors are allocated, see figure 2. This condenser core ensures the capacitance grading of the high voltage condenser bushing [2].
The condenser core is housed with a composite insulator covered by silicone rubber sheds as shown in figure 1. The gap between composite insulator and condenser core is filled with a dry-type N2-based foam and therefore the bushing is completely dry and free of any hazardous fluids and gases such as mineral oil, $SF_6$, $CO_2$ etc. RIS condenser bushings are environmentally friendly in comparison to conventional OIP bushings and even better in regard of LCA compared with RIP bushings.

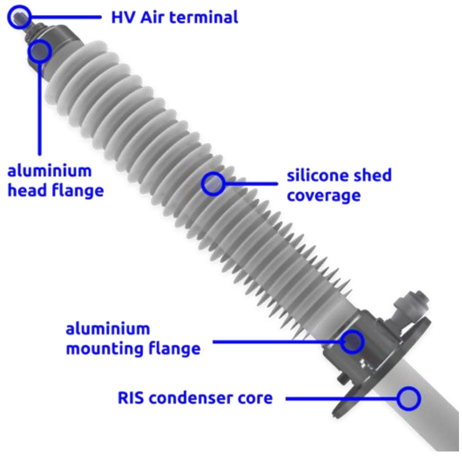



*Figure 1:* *bushing main components.*

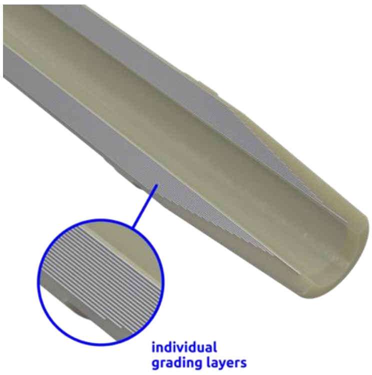



***Figure 2:*** *cross section of RIS condenser core*

## Electrical functionality and material properties of the RIS condenser core

Under the application of high voltage, the capacitance graded condenser bushing is capable to distribute the electrical field evenly as illustrated in figure 3. Therefore, the local electrical field stress can be reduced and stretched over the entire length of the bushing.

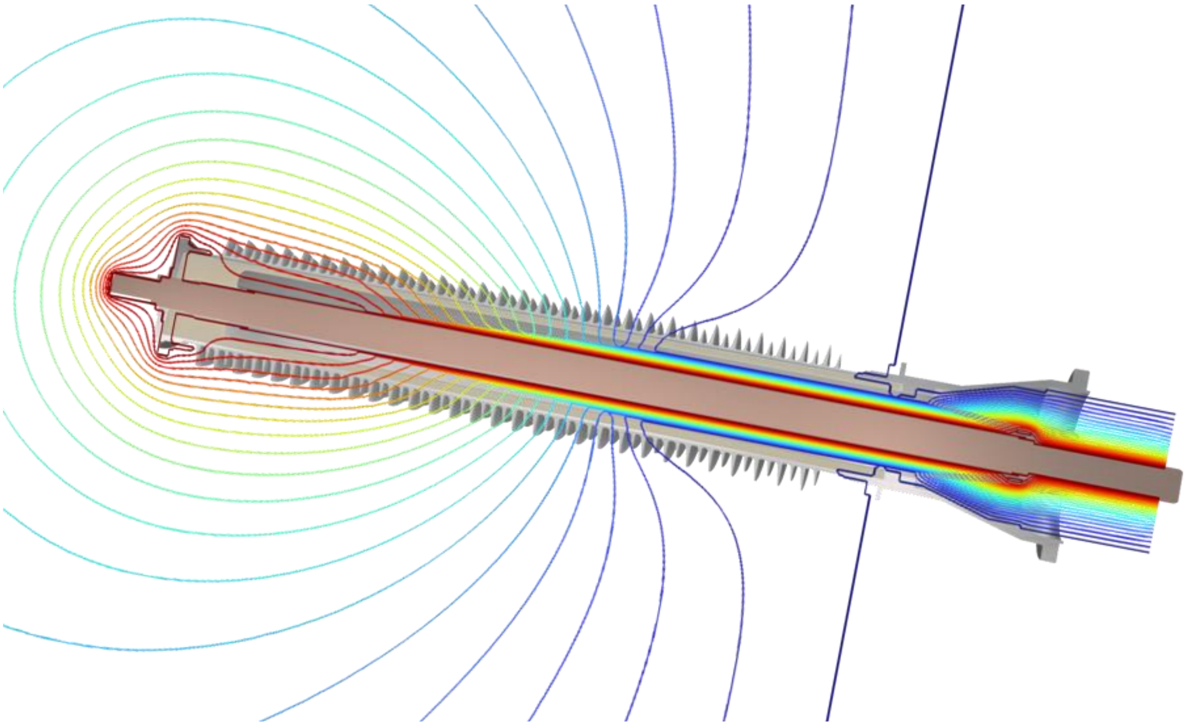
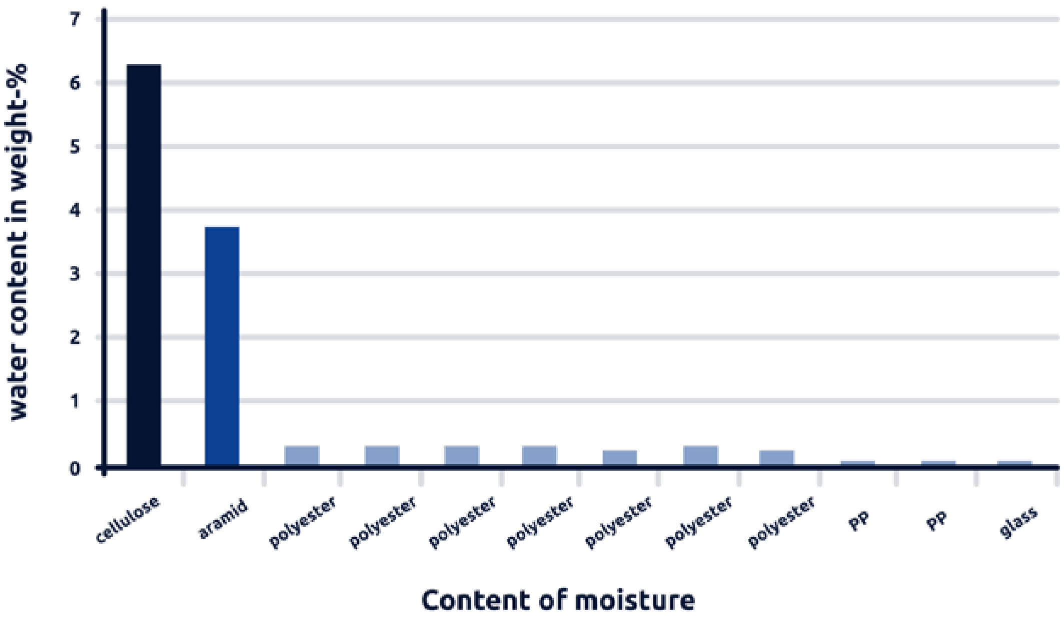


***Figure 3:*** *illustration of equipotential lines*

One of the main material advantages of the RIS condenser core is the non-hydroscopic performance. This ensures that no moister or humidity will ingress inside the condenser core and harm the electrical performance under high voltage. In opposite to paper (used for RIP bushings) which can accumulate humidity easily while exposed to the ambient environment [3]. This aspect is very sensitive for the manufacturing process but also during installation, commissioning and storage of the respective bushings. Figure 4 shows the humidity absorption after storage in water, the results after storage at 23°C und 50 % rel. humidity are for paper: 6,24 % and for synthetic materials: 0,23 - 0,32 %.



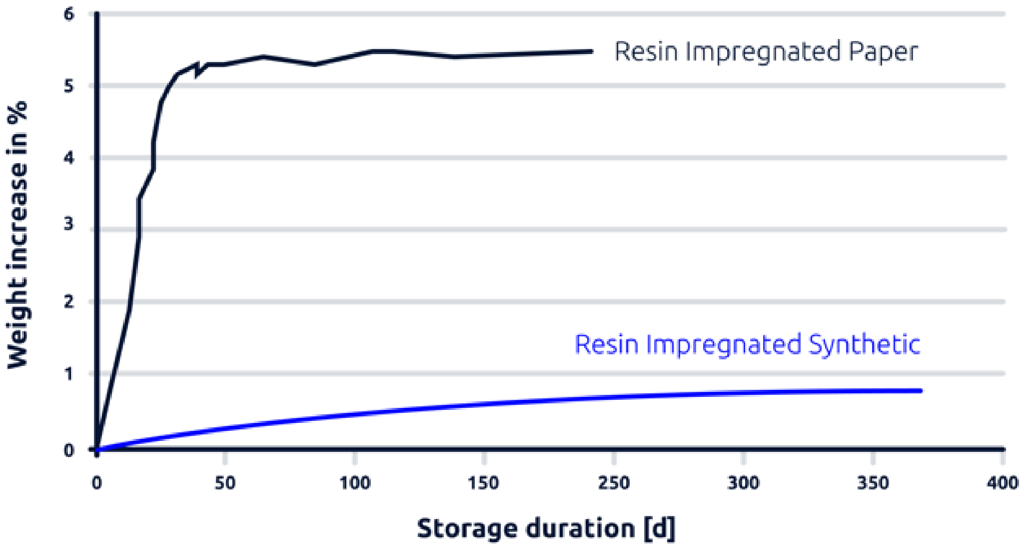




***Figure 4:*** *Humidity absorption behavior after storage in water*

## Qualification of RIS condenser bushings

In fact, the only component of a RIS condenser bushing different from a RIP condenser bushing is the synthetic carrier material for the epoxy resin and the aluminum layers. However, an extensive qualification program is necessary to ensure that all beneficial aspects of the well-established RIP condenser bushing are kept or improved.

As an example, a thermal cycle test with dynamic mechanical load and continuous electrical load was carried out with RIS condenser bushings as shown in figure 5.

The whole test set-up was built up in the climate chamber and enabled 30.000 load cycles of 2500N with a varying ambient temperature between -60°C and +50°C (figure 6). During the test the bushings were continuously stressed with 80% of Up. At each temperature peak the electrical parameters of the bushings were measured (capacitance, dissipation factor and partial discharge). The bushings passed the test program without any failure.

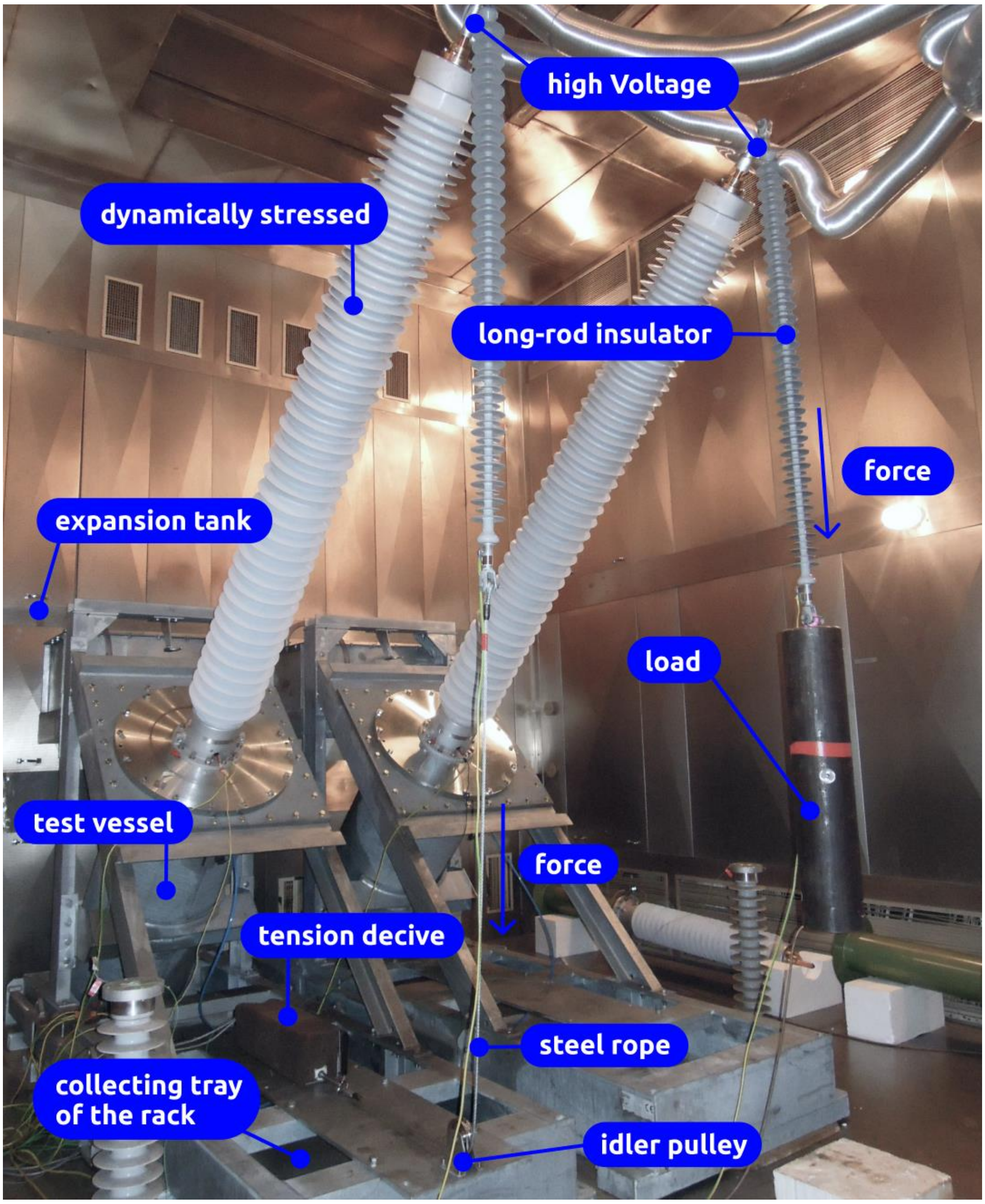



***Figure 5:*** *RIS condenser bushings in a thermal cycle test with dynamic mechanical load and continuous electrical load*

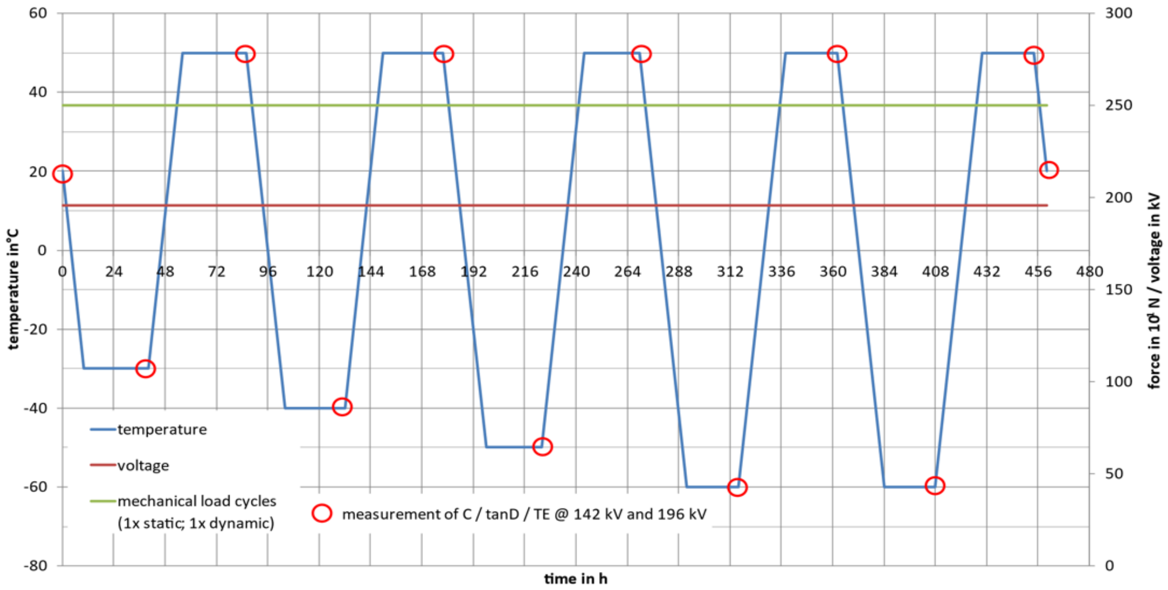



***Figure 6:** Temperature profile during the thermal cycle test*

As a result, RIS condenser bushings are confirmed to cover the full range of both, low ambient temperature up to -60°C and seismic requirement such as RIP condenser bushings. Comparative accelerated aging tests of RIP and RIS condenser cores were caried out in the HSP long-term test laboratory and confirmed that the lifetime of RIS condenser bushings exceeds the lifetime of RIP condenser bushings.

Since the first RIS condenser bushings were installed and commissioned in 2014, more than 2000 RIS condenser bushings are in operation to date with more than 50 million accumulated operating hours and a failure rate of 0%.

## HVDC condenser bushings in RIS technology

For HVDC grids and inter-connections specific equipment is needed such as oil immersed shunt reactors or power converter transformers. To connect such equipment also condenser bushings are required. In this type of application, the DC electrical stress leads to a resistive grading in addition to the capacitive grading of AC electrical stress. Therefore, design and testing of HVDC condenser bushings is elaborated and defined in specific international standards [4]. In order to proof the capabilities of the RIS technology for HVDC applications the development and extensive testing was performed for a 545kV HVDC converter transformer bushing. To verify design and testing the individual test sequences have been performed in parallel with both technologies, RIS and RIP. All applicable type and design tests were finished successfully in 2022. Figure 7 shows the test set-up of the even wetting DC voltage test.

***Figure 7:*** *Type test of the 500kV RIS-HVDC bushing – Even wetting DC voltage test*

**Lifetime cycle assessment**

Becoming more important for TSOs and public utilities is the impact of the environment and the use of eco-friendly components and equipment for a sustainable power transmission and distribution. A validated method to determine the $CO_2$ impact of individual products is the so-called life cycle assessment. With this assessment the carbon footprint will be calculated from the initial sourcing of components to manufacturing, delivery, installation, commissioning, operation, deinstallation and disposal of the respective product. In figure 8 the comparison of carbon footprint between RIP and RIS condenser bushings is shown under the following base line scenario: Total lifetime of 40 years and a realistic anticipated temperature based on average load of 70% as in-service operation conditions. The result is that RIS condenser bushings have a 45,8% lower carbon footprint than RIP condenser bushings. Also the operational losses a significant lower for RIS condenser bushings than for RIP condenser bushings.


***Figure 8:*** *Carbon footprint and operational losses of RIP and RIS condenser bushings*

## Ambient performance of silicone outdoor insulators

Another important aspect is the outdoor performance of condenser graded bushings. Climatic impacts such as heavy wetting, pollution, leakage currents and others may reduce the insulation properties of the bushing. For state-of-the art designs silicone rubber insulated have been introduced also because of easy handling, lower weight, and better outdoor performance. Due to the specific effect of hydrophobicity (figure 9) the surface of silicone rubber materials is water repellent which prevents the entire wetting of the surface and therefore the accumulation of conducting pollution layers is reduced to a minimum. In result the risk of flashovers can be mitigated. As the hydrophobicity effect will also transfer over time to the pollution layer at the insulator surface [5] a high pressure washing of silicone rubber insulated bushings is not recommended and should be avoided. If cleaning of insulator surfaces is recommended reputed supplier offer respective cleaning instructions.

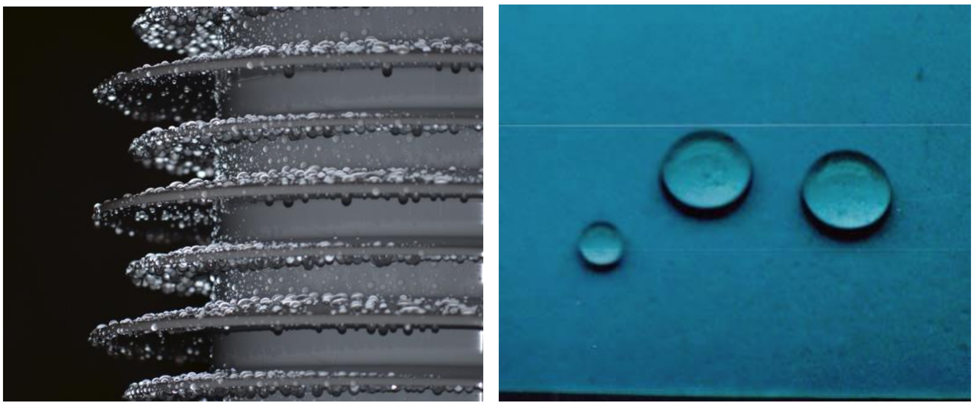


***Figure 9:*** *Hydrophobicity effect on silicone rubber surfaces*

## Conclusion

As discussed and elaborated in this paper RIS condenser bushings are the best choice for the application in high voltage AC and DC transmission and distribution grids. Most advanced in the sense of applying components and manufacturing materials is the utilization of a synthetic nonwoven as the carrier material for the epoxy resin. Such dry-type condenser bushings in RIS technology offer an even better in service performance and advantages when it comes to installation, commissioning and storing of high voltage bushings compered to usual OIP or RIP condenser bushings:

i) No paper and no insulation fluids such as mineral oil or ester fluids
ii) Substantially reduced ageing due to avoidance of organic materials
iii) Higher resistance against humidity -> non-hygroscopic material
iv) Lower dissipation factor compared to RIP bushings and no PD activity in electrical field
v) Homogenous material characteristics – no voids in condenser core
vi) Substantial lower carbon footprint in comparison to OIP and RIP condenser bushings

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