Reliability is an essential request for high-voltage bushings, whose predominant role is to carry high potential current through an earthed enclosure and prevent flashovers to the ground

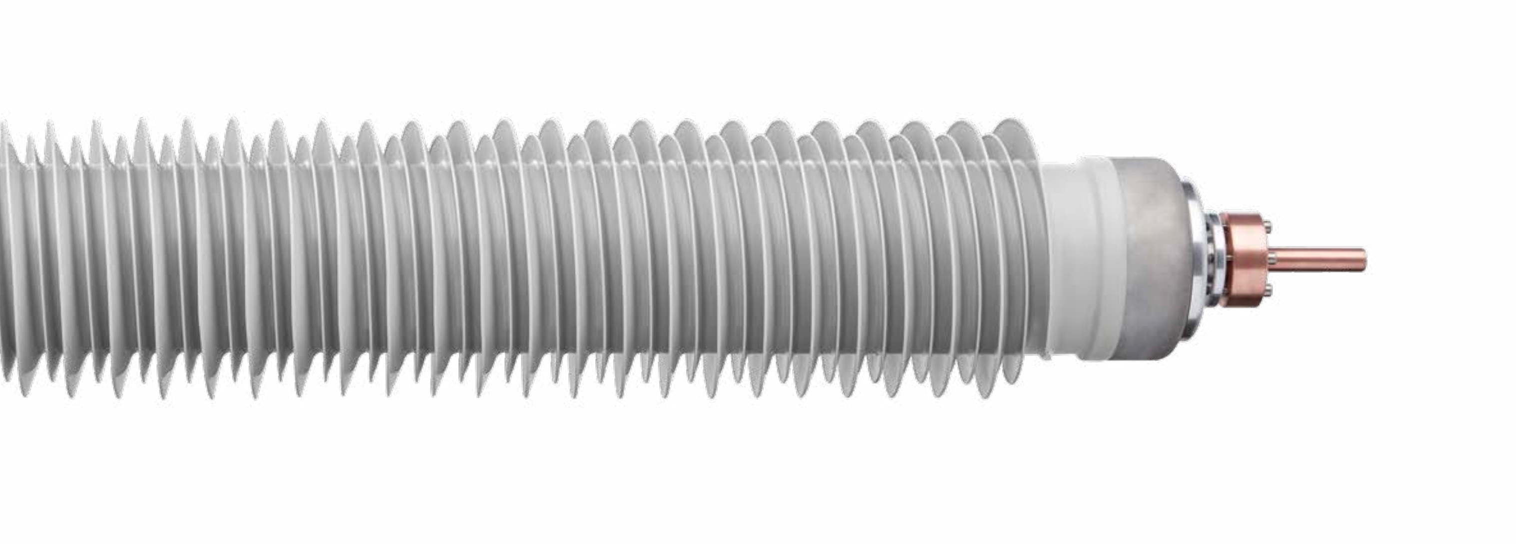
AirRIP® flex – the new and highly configurable dry bushing concept for 245-550 kV systems from Hitachi Energy

Bushings in the electric grid

Reliability and longevity are crucial attributes of the products and services of the energy market. This is often necessitated by the huge capital outlays involved and the punitive expense of downtime resulting from breakdowns or failures. The power transformer, with its exceptionally long lifetime of 50 years or more, is a prime example of the market's response to the need for reliability. This core demand for reliability extends to the myriad components of the electrical network; big or small, each is a critical cog in the wheel. Reliability is also fundamental for high-voltage bushings – whose predominant role is to carry high potential current through an earthed enclosure and prevent flashovers to the ground. Thermal and electrical stress and ambient conditions further emphasize the importance of enabling a prolonged and active life for high voltage bushings.

In addition, bushings need to be configurable to cover as many requirements as possible without affecting lead times; however, special designs are sometimes necessary for covering exceptional requirements and addressing regional issues. These prerequisites form the basis for the new common bushing technol-

Bushings consist of three primary components: outer insulation for minimizing creepage currents and preventing external flashover; inner insulation for distributing the electrical field; and a conductor system for carrying the current



ogy platform, AirRIP® flex, illustrated in Fig. 1.

Bushings in general

High voltage bushings of the capacitance graded type are used for system voltages starting at approximately 36 kV. Bushings consist of three primary components: outer insulation for minimizing creepage currents and preventing external flashover; inner insulation for distributing the electrical field; and a conductor system for carrying the current, as illustrated in Fig. 2. Within the inner insulation, coaxial layers of conducting material are very precisely positioned in an insulating web, resulting in an optimal balance between external flashover and internal puncture strength. To increase the dielectric strength of the inner insulation, bushings are impregnated either with curable epoxy resin (RIP/RIS) or transformer grade mineral oil (OIP).

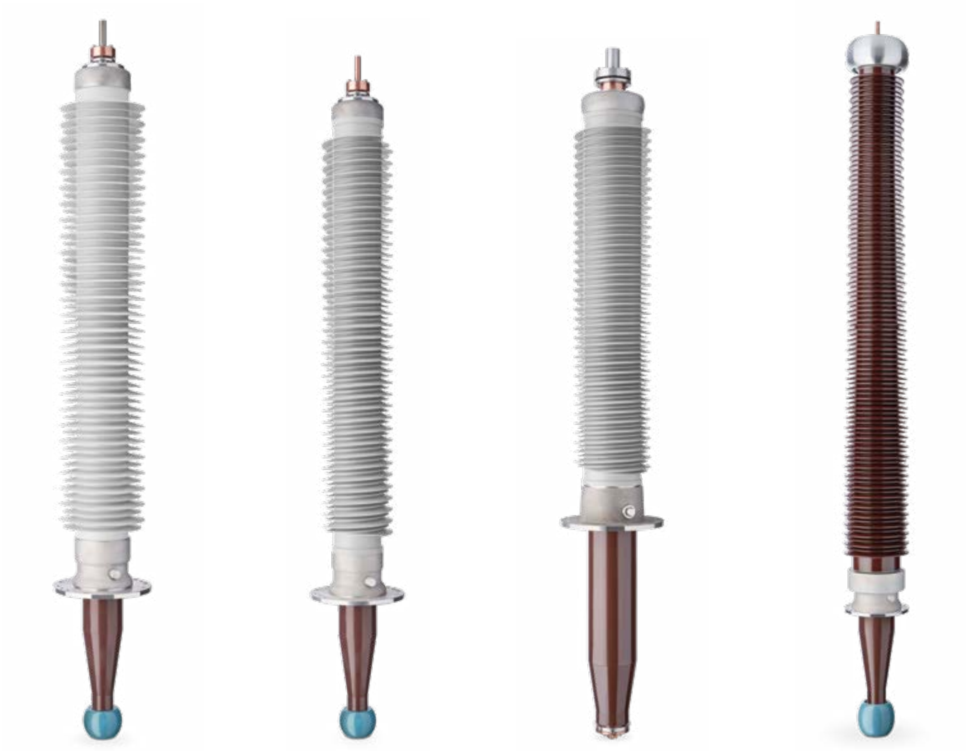


Figure 1. AirRIP® flex concept

A dramatic reduction in the adverse consequences caused by potential bushing failures is the biggest benefit of the completely dry RIP concept for utilities

Bushings for alternating voltages (AC) are standardized under IEC 60137 with regard to the testing of their electrical, thermal, and mechanical properties. The IEC standard commands broad global acceptance but cannot address specific regional issues. For this reason, regional standards deal with application issues such as atmospheric and seismic conditions or, in some cases, the interchangeability of products between different manufacturers. Type testing is performed to verify the various design solutions for each product concept, and the critical steps in the production process for each manufactured unit are verified in routine testing.

Figure 2. Primary bushing components. The outer insulation is to the right, and the inner insulation with the conductor system is to the left. The mounting flange, terminal arrangements and electric shield are also shown.

The design philosophy for AirRIP® flex

The design principles used for the common bushing AirRIP® flex remain essentially the same as when the technology platform for power transformers was developed several decades ago. These tenets are considered to be:

- common design rules based on several factories' experience,
- common design system and design tools,
- common manufacturing processes,
- common quality and failure analysis systems,
- common feedback and continuous improvement programs,
- common training and education systems.

These business concepts have allowed the accumulation and melding of global design and manufacturing experience for continuous process and product improvement.

Concept selection

Some of the important aspects of the inner and outer insulation and conductor systems are outlined below.

Inner insulation

A dramatic reduction in the adverse consequences caused by potential bushing failures is the biggest benefit of the completely dry RIP concept for utilities. Although phase-to-ground flashovers can have many causes – failure of the bushing itself and electrical, mechanical, and thermal stresses from the grid system – flashovers in oil-filled bushings usually produce an explosion resulting in shattered insulators and oil spills. Because completely dry RIP bushings do not contain any highly flammable and energy-rich oil, the risk of fire is largely eliminated [1]. This is unlike some RIP concepts available in the market that are partly filled with oil.

Outer insulation

Besides not being prone to shattering in the event of failures, the preferred composite insulator concepts comprising silicone rubber extruded on filament-wound tubes have a multitude of other positive properties for outer insulation:

- Owing to the chemical structure of the silicone, the insulator's surface is hydrophobic, causing the formation of water droplets on the surface instead of a water path. This reduces creepage currents and consequently erosion and reduces flashover risks under extreme weather conditions.
- The continuous nature of the manufacturing process produces a chemical bond between the tube and insulator. Because both the silicone rubber and filament-wound tube are free of joints, the electrical field distribution is smooth and continuous, with minimal risk of moisture penetration. There are no parting lines either, where salt and pollutants could potentially collect.
- Extrusion also provides the opportunity to optimize the insulator's shed profile for different applications. This results in a further reduced electrical field, which in turn lessens tracking and erosion risks.
- The chosen polymeric insulation material is HTV rubber; this basic material is a high-temperature, vulcanized silicone rubber made from a carefully balanced mixture of pure silicone and an aluminum trihydrate (ATH) filler. In addition to mechanical strength, the ATH filler is also temperature and fire-resistant, and the usage of optimized amounts also speeds up the recovery of its hydrophobic properties after severe weather conditions like heavy rain. Field experience has also shown that HTV rubber is highly resistant to erosion and retains its hydrophobicity for extended periods [2].
- This type of insulator is significantly lighter and mechanically stronger than the corresponding class of ceramic insulators. This is a significant property that helps withstand the effects of earthquakes and short circuits while also limiting the damage during handling.

An HTV rubber concept, with concentric sheds that are injection molded in sections and glued together on a fiberglass cylinder, is also offered as an alternative. Finally, a ceramic alternative is also available to cover as many customer preferences as possible.

Conductor systems

In order to be highly configurable, AirRIP® flexx offers several connection systems to cover as many customer preferences as possible: draw lead, where the current is led through a cable conductor; split removable rod, where the current is led through a removable copper rod generally fitted with a joint, and whose lower section can be pre-installed directly in the transformer turret. The fixed bottom contact type is fitted with aluminum or copper conductors for high current capability and high mechanical performance. Finally, the Quick Connect® (draw rod) connection type is based on a casted conductor tube which provides the current path but allows the pre-mounting of the bottom contact in the transformer turret and easy installation and removal of the bushing at the site. See Fig. 3.

In order to be highly configurable, AirRIP® flex offers several connection systems to cover as many customer preferences as possible

Product and manufacturing considerations

Hitachi Energy´s objective has been to replace several existing RIP bushings families with one optimized global product platform. The concept is intended to form a solid basis for the IEC markets and be easily adaptable to other markets like India, Russia, and China, among others. The product performance and dimensions will guarantee interchangeability with existing products, and the platform will permit a wide range of configurations to meet all customers' requirements for accessories and interfaces with the transformer. Furthermore, hundreds of different OIP bushings have been considered in order to address the retrofit market and meet burgeoning market demand for upgradation from oil-insulated bushings to completely dry solutions.

Figure 3. Quick Connect® system

Another major objective was to minimize the number of variants of the main components to allow modularization and thus achieve technical solutions. In total, the platform is based on approximately 500 components that allow more than 250,000 final bushing configurations, as illustrated in Fig. 4.

The harmonization of assembly methods and manufacturing has driven the development of the platform entirely, from the design phase up to its final release in the market; this has allowed the AirRIP® flex concept to be manufactured in all factories using common manufacturing processes and quality systems.

Technical challenges and mitigations

For a new bushing platform to meet both industry standards and market requirements, numerous tests must be performed. Therefore, the full qualification is based on more than 90 different type-tests that are performed at accredited external laboratories, in addition to Hitachi's in-house tests. The use of computer simulations allows the optimization of products and a reduction in the time required to perform the standard tests. Whenever possible, the

Hitachi Energy´s objective has been to replace several existing RIP bushings families with one optimized global product platform - AirRIP® flex

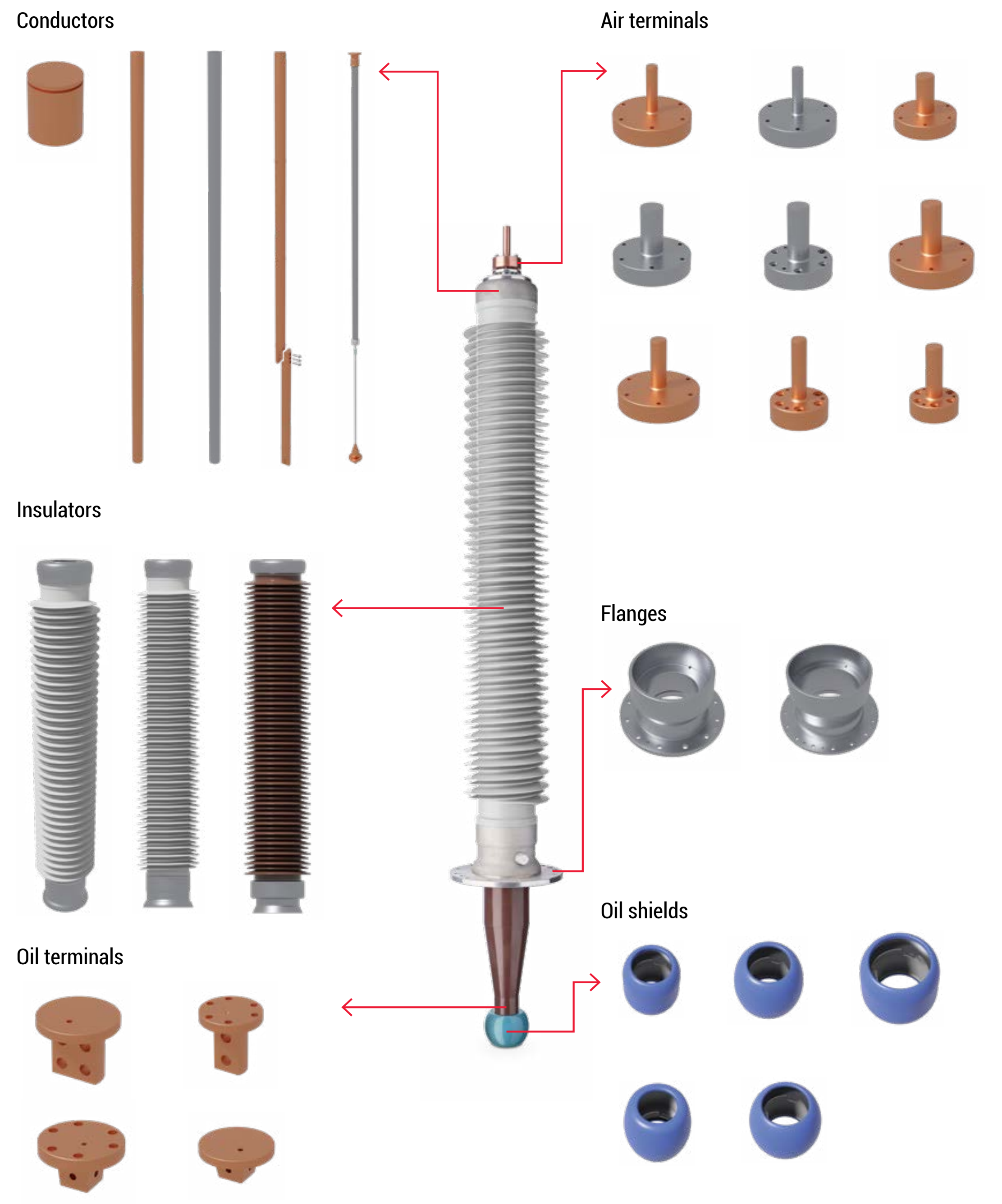


Figure 4. Modularization concept

The use of computer simulations allows the optimization of products and a reduction in the time required to perform the standard tests

advanced simulation methods and models have been built with a parametric approach, resulting in 35 complete thermal models covering hundreds of different geometries and related current ratings.

Mechanical engineering

The guiding principle has been to minimize material consumption with retained compliance with strength requirements. To achieve this, the bushing is considered as a single system in which all parts together provide the product's strength. This entails that the respective sub-components must be in strict compliance with the set requirements. Mechanical engineering has been extensive, especially regarding seismic requirements. A solid base of experience from existing bushings types has been of great benefit. Nonetheless, many advanced finite element analyses (FEM) have been conducted.

Electrical engineering

A dielectric simulation is a valid tool for design optimization and for the assessment of the stress experienced by the bushing in different configurations. The dielectric simulation considers the diverse arrangements described by the standards. Fig. 5 demonstrates the dielectric simulation of a switching impulse test, which is critical for airside evaluations, especially in wet conditions. Stress values can be compared with similar previously designed products in order to validate the design, which is the result of years of experience and expertise.

Thermal engineering

The rated current can be simulated to predict the maximum temperature in case of overload or other conditions which are beyond the scope of the standard temperature rise test. Before starting a simulation campaign for a new bushing platform, the simulation models of the different types of connections are validated through real measurements. The validated models can then guarantee suitable predictability in case of different load conditions and ambient temperatures.

Manufacturing

Global manufacturing is enabled by the harmonization of all processes, from the selection of global suppliers and logistic concepts, through the harmonization of quality, testing, and safety requirements, to tools, processes, and assembly in the factories. In some cases, new and dedicated manufacturing and test equipment have been set up. The release of the global platform has enabled the sharing of best practices from different sites, thus enhancing technical ownership and consolidating the highest standards of quality.

Ensuring product and service reliability

Product selection, manuals, and general information

When designing a transformer, the search for the right bushing can be a complex

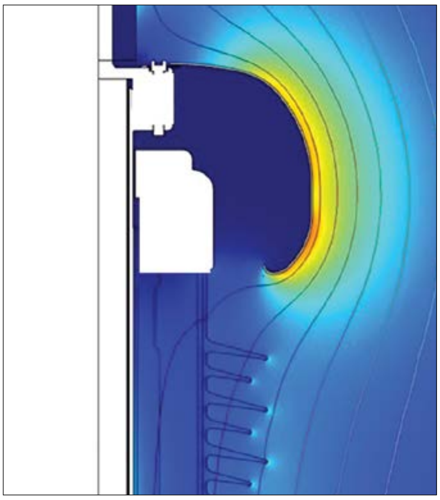


Figure 5. Example of dielectric simulation

Hitachi Energy's online selection tool COMPAS will provide both assistance in finding the right variant for each application and additional information like technical data and drawings for the product

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In addition to regular installation and commission manuals, general documentation on a variety of subjects such as condition assessment, tests under extreme conditions, and long-term service experience are also readily available based on the company's vast pool of experience accumulated from over a century of bushing production.

Conclusion

Hitachi Energy's common concept for completely dry AC bushings is based on common design rules and the experience of several factories which have been producing bushings since 1908. Common design systems and tools, manufacturing processes and quality systems are essential prerequisites for the introduction of this bushing. The full qualification is based on a large number of tests in combination with computer simulations to optimize the product and reduce time-to-market. This business concept has allowed the global accumulation of design and manufacturing experience and enabled continuous process and product improvements.

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See more about AirRIP® flex here:
AC bushing type AirRIP® flex 245-550 kV | Hitachi Energy

Authors

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Teresa Gargano works as R&D Manager for bushings at Hitachi Energy in Switzerland. She has a decade-long experience in HV bushings, contributing to the development of new products and new technologies with a special focus on the transformer as the final application. She drives global R&D projects, enhancing processes and tools, including FEM analysis as a predictive method for the assessment of components performance in the testing phase or in operation. She is a member of National IEC technical subcommittee 36A.