TRANSFORMERS MAGAZINE

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Dear Readers,

It is my pleasure to present you with the special edition of Transformers Magazine dedicated to bushings.

Following the collection and preparation of the materials for this edition, I set fourth to create a summary that would highlight in brief the most important points on the subject of bushings. While doing so, I spoke to a number of experts, among them an experienced transformer designer from a well-known transformer company, who attracted my attention with an interesting claim that in the past few decades we haven't seen a single significant leap in the bushings technology. And by the leap he didn't only refer to natural movements in the evolution of such a product, such as the advancement in the material technology where better materials would replace the existing ones, or expanding the voltage level of the product, but he also referred to a more comprehensive, quantum leap in the bushings technology.

Nevertheless, I still find it impressive to see bushings for 1100 kV and 1200 kV voltage levels. If we think about the scale of the impact of the development of such advanced products on the industry as a whole, it is probably true to say that only a small number of us will ever come to encounter and work with these solutions, either directly or indirectly, so the real impact of this development may be expected to remain quite limited.

We have, however, seen significant advancements in the RIP and RIS technologies, and particularly in the fields of monitoring and diagnostics, and these advances are more likely to have a wider impact on the industry.

Regardless of their scale of impact, all these advancements are important and worthy of attention. Without transformer bushings for a certain voltage level, it wouldn't be possible to build a grid of that voltage level, despite the fact that these bushings probably have the same or very similar functionalities as well as handling, maintenance and other procedures as the transformer bushings of a lower voltage level. New materials can simplify the usage of a product, requiring less maintenance, while new monitoring and diagnostic methods can significantly enhance failure prevention and help improve asset management.

In relation to the transformer, the bushing is a relatively simple and cheap component, but its impact on the transformer life and reliability is enormous, which calls for a greater emphasis on the development of the technology

Still, if I had to single out one solution that I expect to have the greatest impact on the industry, I wouldn't choose any of the mentioned ones. In my humble opinion, among the developments we have recently witnessed in the realm of bushings, the "pluggable bushing" concept is most potent to influence not only the future of the bushings, but also the future of the transformer and the way it is used. Our regular editions have dealt quite extensively with this concept, and beside everything that has been published about it, I still think that there are more benefits of this concept yet to be identified.

Just the fact that a bushing can now

be replaced without needing to open the transformer's active part is enough to excite interest of any inquisitive or innovative mind.

I would like to point to one more issue that has been raised by almost every author in this edition, each from his or her own perspective – a high share of transformer failures that are caused by bushing faults, especially those ending in explosions and fire. The mere fact that a relatively simple and cheap component in relation to the complexity and price of the transformer can have such an enormous impact on its reliability and life span is a motive in itself for all stakeholders, from utility companies through bushing manufacturers to material producers etc., to place a greater emphasis on the development of the technology. The important role of the bushings in ensuring physical security only strengthens that motive.

We open this special edition of the magazine with an interview with one of the innovators in the bushings industry, and continue with a wide range of articles on a number of relevant topics related to bushings, including market reviews, discussions on monitoring and diagnostic methods, risk mitigation, maintenance, technology, and more. All this should provide a deeper insight into the current issues in the bushings technology and the relevance of the future developments in this industry.

Last but not least, I would like to take this occasion to extend my heartfelt gratitude to our Guest Editors for their thorough and quality peer review of a large amount of materials in quite a limited space of time.

Equally, my wholehearted thanks go to all authors who recognized the importance of taking part in this special edition, as well as all partners for their support in the realization of this project.

Enjoy reading this special edition of Transformers Magazine!

Mladen Banovic, Editor-in-Chief

Foreward to the Special Edition

Bushings are a very important part for a great deal of HV equipment. Without bushings, actual large power transformers are unthinkable. Throughout history they have shared their development with transformers and other representatives of HV technology.

Initially, bushings were a kind of solid type bushings often made from porcelain with an inserted conductor. Similar bushings are still frequently used in distribution networks for system voltages up to 52 kV due to their simplicity, reliability and low price. However, for only a slightly higher voltage they become impractical because of a very steep increase in size. Instead, for higher voltages a condenser bushing type is used today. Inside condenser type bushings, there are conductive electrodes that are used for radial and axial electrical field grading. One of the oldest descriptions of the condenser type bushing dates back to 1906. What was then described as an "innovation" was in fact a 200 kV condenser type bushing used as part of an HV test transformer. Soon after, in 1908, the production of capacitive graded bushings started: first the coarse graded and afterwards fine graded bushings in RBP technology. This solution was limited because of a relatively high level of partial discharge (PD) generated in small air pockets, which was inevitable for this technology.

HV bushings for higher temperatures should be developed

OIP bushings were introduced around 1944 to fulfil the needs for higher voltages and lower PD level. Then around 1950, the first RIP bushing was produced. Today, OIP and RIP bushings are produced up to the highest AC and DC voltages – approximately up to 1200 kV and 35 kA.

Some time around 1990, a silicone rubber on a glass fibre epoxy tube was introduced as a bushing upper envelope with an aim to eliminate some disadvantages of a porcelain upper envelope that had been in use until then.

Recent bushing developments include applying silicone sheds directly on the RIP body (around 2005) and replacement of paper with inorganic material (RIS bushings, around 2012).

Looking into the future, it should be stated that actual power transformers with solid and liquid high temperature materials have allowable top oil temperature greater than the highest temperature allowed for all HV bushing types listed in standards, so HV bushings for higher temperatures should be developed.

Bushings are among the most frequent transformer failure cause. According to data from various research studies and electric power utilities, they cause from 5 to 50 % of the total number of transformer failures. Bushing failures are the most common cause of transformer fires that can lead to huge collateral and ecological damages at the switchyard. Bushings are a transformer's crucial part and one transformer can have more than 10 bushings. A failure of any of them has a transformer failure as a consequence. A bushing explosion can damage the transformer in many ways. Upper porcelain envelope burst launches fragments of it at an enormous speed with destructive power. The burst of the bushing's lower part damages a transformer in such a way that the conductive and burned debris of the condenser body pollutes its active part. Cleaning transformer's active part from bushing fragments is a difficult job with doubtful results.

Bushings are normally mounted on the hottest part of the transformer and they are exposed to both the highest and the lowest temperatures as well as the atmospheric conditions. Animal attacks (rodents, birds, monkeys, etc.) to the silicone shed can seriously affect bushing properties. This, combined with mechanical forces, results in huge demands on the bushing insulation and sealing system. It should also be mentioned that the electrical field strength in the bushings HV condenser body is among the highest in HV technology. HV bushings are thin and long and therefore a fragile structure, sensitive to mechanical forces due to switchyard connection, short circuits, earthquakes or vandalism.

In terms of preventing bushings as well as transformer failure, bushings are subjected to periodic (off-line) and continuous (on-line) condition diagnostics. A lot of methods, traditional or recently developed, are used with various effectiveness. Nowadays, with expansion of bushing monitoring systems (continuous diagnostics), new possibilities emerge to improve transformer service reliability and availability. However, new challenges appear as well, as can be seen from the papers in this edition.

Antun Mikulecky, PhD, Guest Editor