BREAKTHROUGH IN PROTECTION WHEN MONITORING BUSHINGS

The energy transition is a huge shift from fossil-based to fossil-free sources. This will mean moving to an energy system with electricity as the backbone that can handle a growing demand from industry, buildings and transportation. We estimate that by 2050 we will need four times the generation capacity and our electrical power systems will need to transfer three times more electrical energy than today.

Highlighting that today's energy system is deficient in security, equity and sustainability is not about blaming the old system – we recognize that each era has its own economic and social constraints and its own technological limits. Instead, we see these deficiencies as a recognition that the power system of tomorrow cannot be the same as today, they show our imperatives for shaping a power system that is fit for our future.

Highlighting that today's energy system is deficient in security, equity and sustainability is not about blaming the old system – we recognize that each era has its own economic and social constraints and its own technological limits.

We must **strengthen** the power system, making it more reliable and secure; **expand** it in both reach and scalability; and **evolve** it to be more sustainable and resilient.

Our role in this is critical, our purpose at Hitachi Energy is clear and crucial – to **advance a sustainable energy future for all**. This article will share how we combined our expertise in bushings and transformer monitoring to make the grid more resilient.

Photo: Hitachi Energy

Transients affecting bushings equipped with monitoring equipment

High voltage capacitance graded bushings are critical components of power systems, and their failure can result in significant economic and safety consequences. According to CIGRE studies 5 to 50% transformer failures are bushing related, and this percentage increase when we look at shunt reactors failures1. A prominent failure mode is overstressing the bushing insulation, a phenomenon that often happens in combination with transients or very fast transients (VFT) in the grid.

Transients and very fast transients (VFT) are high frequency electrical disturbances that occur in power systems and can lead to the degradation of components such as bushings. The transient voltages are created in renewables applications and mostly from switching operations of breakers and disconnector operations in gas insulated switchgear (GIS) but also from harmonics generated by power electronics.

Transients and very fast transients (VFT) are high frequency electrical disturbances that occur in power systems and can lead to the degradation of components such as bushings.

For safe bushing operation, it is important that the main insulation is properly earthed. Most commonly this is done via a lid on the tap connecting the outermost conduction layer to the earthed flange. When exposed to transients, very fast transients or other high-frequency events, maintaining low impedance to earth is crucial. In cases with failures due to high impedance to earth, the failures occur in the tap region, cables connected to the tap or between the outmost layer and earth.

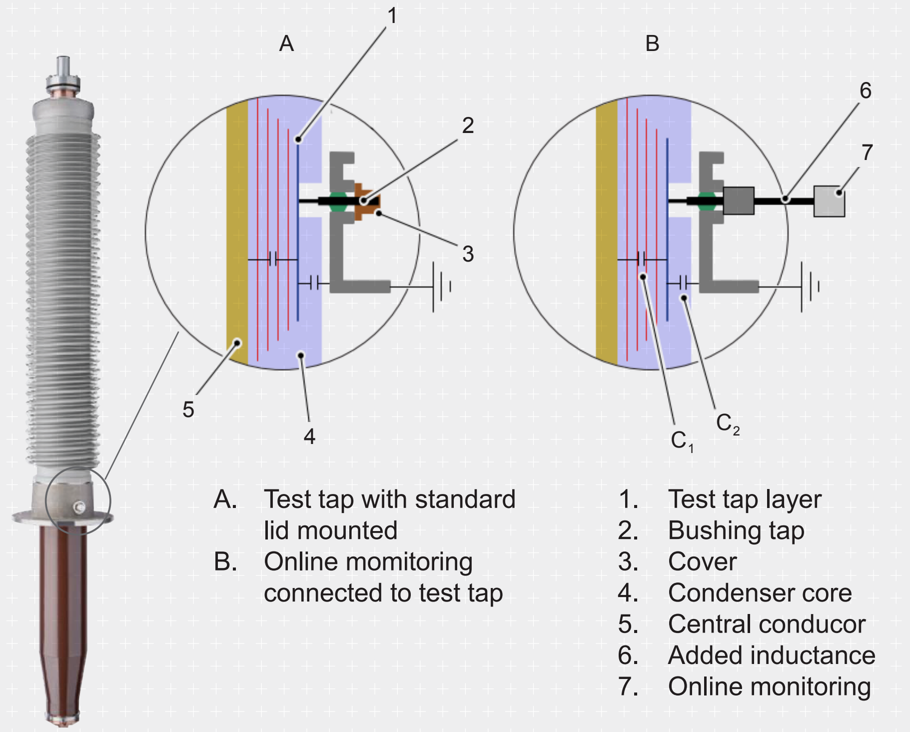

Figure 1
Principal design of a test tap. Earth connection is done via the lid (A) or via monitoring equipment (B).

With increasing complexity in the grid, transformers are also used for improving power quality and network management, and today this means much greater connectivity and digitalization. Hitachi Energy strongly supports the adoption of high-quality monitoring equipment, including our TXpert Hub, to enhance the reliability of electrical systems and support our customers in their maintenance. However, it's important to acknowledge that most bushing monitoring systems require connection to the inner components of a capacitance graded bushing through the tap. When the earthing cover is removed from the tap, it exposes the latter to a new physical environment controlled by the monitoring equipment. The application, grid topology and impedance should be carefully evaluated when considering the implementation of any monitoring system.

Monitoring equipment is usually connected to the bushing tap to measure properties of the main insulation such as capacitance, C1, loss factor (tan δ) or partial discharge. This usually causes an increase in the total impedance of the tap, increasing the risk of failures in service. Our studies have shown that most current online monitoring solutions offered on the market have insufficient protection to safeguard the bushings from the added impedance to earth in combination with VFT.

To illustrate the importance to understand the bushing operational environment, our service teams have worked with several customers during failure investigations where bushing monitoring systems have been involved. Our teams have conducted field and laboratory measurements, and extensive simulations.

We discovered that in several cases, due to the station layout in combination with SF6 breakers (and in many cases GIS switchgear), the bushing was exposed to high frequency transients. Together with the customer it was concluded that this created voltage peaks in the test tap region much higher than the designed limits, with durations between ten to hundred nanoseconds, due to the added impedance of the bushing monitoring system.

To mitigate these issues, it is crucial to minimize the impedance between the test tap and the earthing point. This can be achieved by reducing the impedance of the cable or any attached measuring equipment. The most effective solution, offering the lowest impedance, is the lid specifically designed for the bushing. However, when additional monitoring equipment needs to be attached to the test tap, it is important to maintain control over the impedance to earth.

Figure 2
Picture of failed 400 kV RIP bushing installed on a shunt reactor with to high impedance to earth and exposed to VFT.and exposed to VFT.

Photo: Hitachi Energy, Shutterstock

Our extensive studies and full-scale tests made on most devices available on the market, showed an inability to fulfill our requirements. Leading us to push the boundaries and develop a patented innovative solution.

Table 1 – Classes and shapes of overvoltages, standard voltage shapes and standard withstand voltage tests

Class	Low frequency		Transient		
	Continuous	Temporary	Slow-front	Fast-front	Very-fast-front
Voltage or over-voltage shapes					
Range of voltage or over-voltage shapes	f = 50 Hz or 60 Hz $T_t \geq$ 3 600s	10 Hz < f < 500 Hz 0,02 s $\leq T_t \leq$ 3 600 s	20 µs < $T_p \leq$ 5 000 µs $T_2 \leq$ 20 ms	0,1 µs < $T_1 \leq$ 20 µs $T_2 \leq$ 300 µs	$T_f \leq$ 100 ns 0,3 MHz < f_1 < 100 MHz 30 kHz < f_2 < 300 kHz
Standard voltage shapes	f = 50 Hz or 60 Hz T_t [a]	48 Hz $\leq f \leq$ 62 Hz T_t = 60 s	T_p = 250 µs T_2 = 2 500 µs	T_1 = 1,2 µs T_2 = 50 µs	a
Standard withstand voltage test	a	Short-duration power frequency test	Switching impulse test	Lightning impulse test	a

[a] To be specified by the relevant apparatus committees.

Figure 3
Table 1 from IEC 60071-1, no standard voltage shapes nor tests are defined for transients or very fast transients with rise times below 100 ns and ringing frequency above 0.3 MHz.

The Bushing Tap Protector

We have demonstrated that it is crucial to control the voltage carefully when the tap of a bushing is not solidly earthed to prevent the operating voltage or transient voltages from reaching dangerous levels. The acceptable voltage levels vary depending on the specific design of the bushing. While most monitoring systems incorporate voltage protection mechanisms, it is essential for the user to verify that the chosen scheme offers adequate long-term protection, having in mind also that in standards such as IEC there are no standardized tests for transients and very fast transients.

Our extensive studies and full-scale tests made on most devices available on the market, showed an inability to fulfill our requirements. Leading us to push the boundaries and develop a patented innovative solution. We call it the bushing tap protector (BTP).

The main objective for the BTP is to reduce the impedance to earth during a transient event to protect the bushing. At the same time, it is does not affect signals of both high and low frequencies at voltage levels below 200 V as not to interfere with the monitoring systems. The BTP protection is fast enough to handle the fast rise times of VFT, 1-10 ns, as well as slower transients in the range of a few microseconds. It also needs to handle surge currents of up to 40 kA while limiting the transient pulses inside the test tap below the withstand level of the insulation. Different variants of the BTP exist to accommodate different tap designs but obtaining the same protection level.

The Bushing Tap Protector will be offered together with either Hitachi Energy Bushings or TXpert Hub monitoring systems.

TXpert Hub is the heart of Hitachi Energy's TXpert Ecosystem. It enables the user to take simple steps to digitalize a transformer; liquid filled or dry; new or retrofit; regardless of its brand.

TXpert Hub collects data from sensors, watches interdependencies, and trends their evolution based on configurable thresholds. It acts as the cyber secure bridge for communication going up from or down to the transformer, allowing safe and remote monitoring.

The new generation of TXpert Hub, powered by the latest CoreTec technology, has been built from the ground up to ease transformer digitalization, focusing on:

- Incorporating the operative experience from users of earlier versions of the system since 1991,
- The application of the latest technologies in communications and cyber security,
- Off-the-shelf retrofit solutions for dry, distribution and power transformers.

As a global leader in bushing and transformer digitalization, Hitachi Energy highly recommends the use of the tap protector, independent of the application or the site topology. The device will be showcased in May 2024 at CIWEME in Berlin and IEEE in Anaheim, to allow our customers and partners to see it and discuss pilot installations.

Figure 4
Pictures of two of the different designs of the BTP mounted on bushings.

Figure 5
TXpert Hub PT Basic+ includes bushing monitoring and will be offered with the Bushing Tap Protector

Photo: Hitachi Energy, Shutterstock

HITACHI
Inspire the Next

Hitachi Energy

Dr. **Henrik Löfås** is a Product Specialist for bushings at Hitachi Energy in Sweden and has 10 years of professional experience in the area, including design, R&D, engineering solutions and testing. He started as a scientist in the corporate research organization and later moved to the engineering. He has also been heavily involved in failure investigations and questions related to condition assessment of aged bushings. He is a member of the PT 36414 working group within IEC TC 36 as well as the newly initiated CIGRE WG A2.68. Henrik has a PhD and a M. Sc. degree both from Uppsala University, Sweden.

Lony Tehini is Hitachi Energy's Global Product Manager for transformer accessories. His experience in product management and sales over the last 10 years covers transformer conventional and digital components and services. He currently serves on the Canadian Electricity Advisory Council. Lony is a professional engineer with a degree in electrical engineering from McGill University.

References

[1] CIGRE studies TB 755/2019
[2] "Impact of VFT on Bushings & Necessary Protection when Using On-line Monitoring", H. Löfås and R. Hedlund, INMR conference 2023
[3] "Risk Mitigation through Transient Protection of Transformer Bushings when Using Online Monitoring", H. Löfås, R. Berg, L. Jonsson and R. Hedlund, to be presented at EIC 2024