Sustainability without compromises

Pioneering instrument transformers with biodegradable liquids

ABSTRACT

There is a very small amount of detailed experience available regarding instrument transformers filled with biodegradable liquids. In an effort to make their entire high-voltage product line more sustainable, thus providing considerable added value, Končar – Instrument Transformers, decided to implement all available biodegradable liquid technologies into their instrument transformers. While it may seem trivial, there is extensive dielectric, thermal, climatic and material compatibility testing that needs to be done, before a dielectric liquid can be approved for use. That being said, the aim of this article is to give a brief overview of performed tests and gathered data. The focus will be on prototypes filled with two different types of biodegradable liquids: synthetic ester MIDEL 7131 and bio-hydrocarbon-based oil Nynas Nytro BIO 300X. Both of the liquids successfully completed the entire testing cycle and are considered approved for commercial use.

KEYWORDS:

Instrument transformers, biodegradable liquids, dielectric performance, simulated ageing, internal arc

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Končar Instrument Transformers has shifted into higher gear by producing several 110 to 400 kV prototypes filled with both MIDEL 7131 and Nynas Nytro BIO 300X liquids, setting the basis for the new products

Implemetnation of biodegradable liquids is the next evolutionary step in the instrument transformer design

1. Introduction

Implementation of biodegradable liquids isn't something new in Končar Instrument transformers. The company has already started experimenting with alternative liquids in 2016 when it produced its first prototypes (110 kV CT and VT) filled with MIDEL 7131. Even though there was no tangible feedback from the market at the time, the stage was set for future endeavours.

In the past couple of years, the company has shifted into higher gear by producing several prototypes ranging from 110 to 400 kV rated voltage and including a spectre of instrument transformer types (CTs, inductive VTs, combined units and SSVTs) filled with both MIDEL 7131 and Nynas Nytro BIO 300X. These instrument transformers with reduced environmental impact became the poster children of the _Green_Line_ product range (Fig. 1).

This product range combines the benefits of biodegradable liquid properties, such as reduced environmental effects (on soil, water and air) and reduction of carbon footprint, with all of the advantages of Končar design. As there can't be any compromise regarding good and healthy environmental practices, there wasn't any compromise regarding Končar design. The prototypes were produced using the same design as the units with conventional mineral oil. What had to be done in order to successfully combine these two concepts shall be explained in the article ahead.

2. Available biodegradable "technologies"

As stated above, the company's first experience with biodegradable liquids was with MIDEL 7131, a synthetic ester, so it was natural to follow up on the previous experience. The second liquid, Nynas Nytro BIO 300X (which is a bio-based carbon isoparaffinic oil)

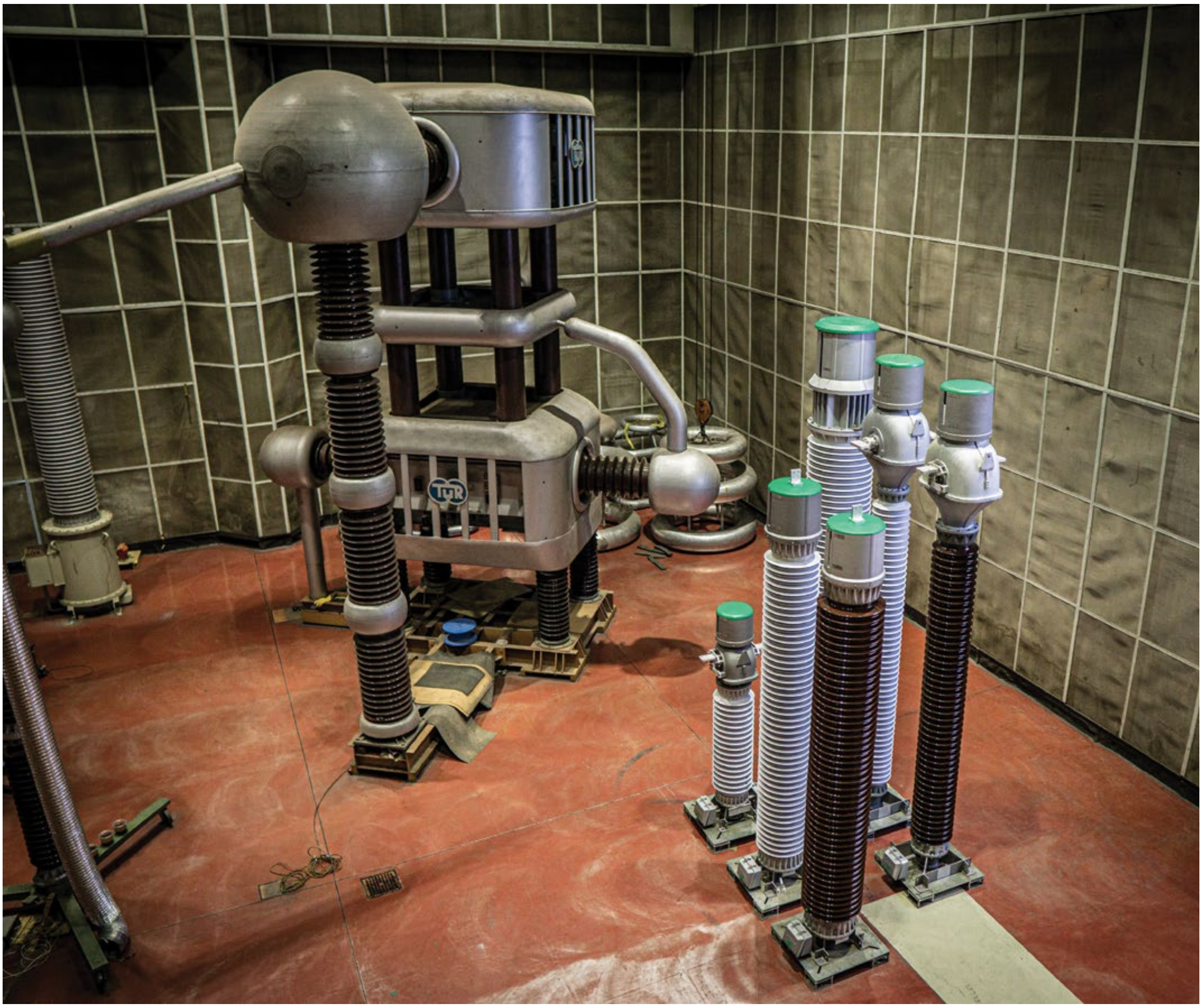

Figure 1 Prototypes of the _Green_Line_ product range

was chosen because of its outstanding chemical properties and negative carbon footprint. It is worth mentioning that prototypes filled with Cargill FR3 (natural ester) and Shell Diala S5 BD (GTL-based biodegradable oil) are scheduled to be produced and tested during 2023.

3. The situation at hand

Instrument transformers function as "frontline" equipment in the power system as they are positioned directly after the disconnector, meaning they come under extreme dielectric stress due to transients and common disconnector switching operations during their operational lifetime.

Although there is a lot of experience with the implementation of biodegradable liquids in power and distribution transformers [1], the instrument transformer field is a sort of "terra incognita" regarding this topic. The same conclusion derived from experience with power transformers can't be directly translated into instrument transformers. The reason behind this is that instrument transformers have a homogenous paper-oil type of insulation rather than a heterogeneous oil-paper barrier type as power transformers have. Another reason is heat transfer which in instrument transformers is mostly through conduction, not convection nor directed flow as in power transformers.

Having in mind the severe dielectric stress and lack of historical experience, extensive and additional testing of instrument transformers needed to be done in order to verify the insulation system of the new

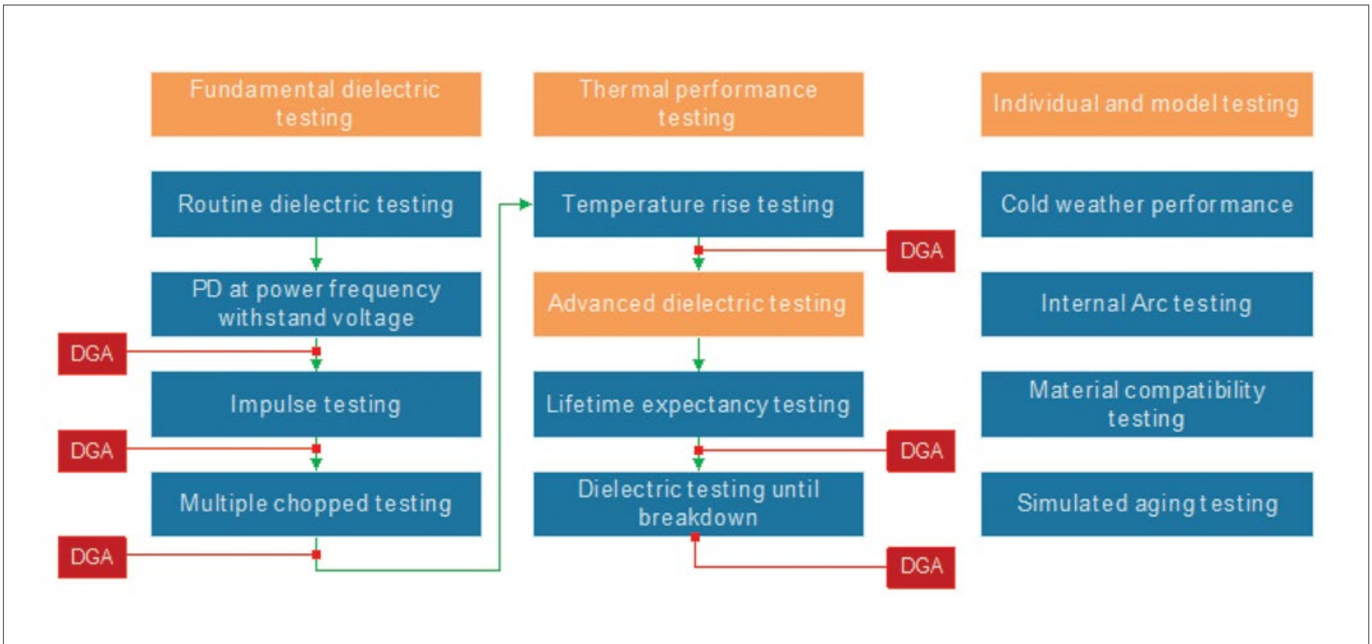

Figure 2. Scope of testing performed on each instrument transformer type

> **Thorough testing had to be performed in order to evaluate the influence of biodegradable liquids on insulation design**

product range. In parallel, a complete map of compatibility material was performed. The array and consecution of the performed tests are shown in Fig. 2, with DGA being performed after each of the tests. The article will not go into detail about every test performed but shall focus on the dielectric and internal arc tests.

4. Dielectric tests

4.1 Routine and type tests

The prototype units were routine and type tested according to IEC or IEEE standards, depending on what specification the prototype was designed. For example, the 110 kV combined unit VAU-123 filled with BIO 300X was tested according to IEC because it was designed according to Austrian specification while the 220 kV SSVT unit VPT-245 filled with BIO 300X was tested according to IEEE since it was designed having a US specification in mind. All of the units passed routine and type tests successfully, including having partial discharges below 10 pC at power-frequency withstand voltage.

4.2 Multiple chopped impulse testing

Multiple chopped impulse testing is a heavy-hitting dielectric test since it simulates current interruption with a disconnector. The test was performed with 600 negative chopped impulses with 70 % to 80 % of the wave amplitude, depending on whether it is performed according to IEC or IEEE standards. The test procedure was coordinated and performed according to the new methodology as outlined in the CIGRE WGA3.42 [2]. The test is deemed to be successful when no breakdown occurs, and gas rises are within standard-prescribed limits. In Fig. 3., several DGA results are shown with the outer outline being the prescribed limits and the green fill being the measured values. As it is clear from the results, the units passed the test successfully.

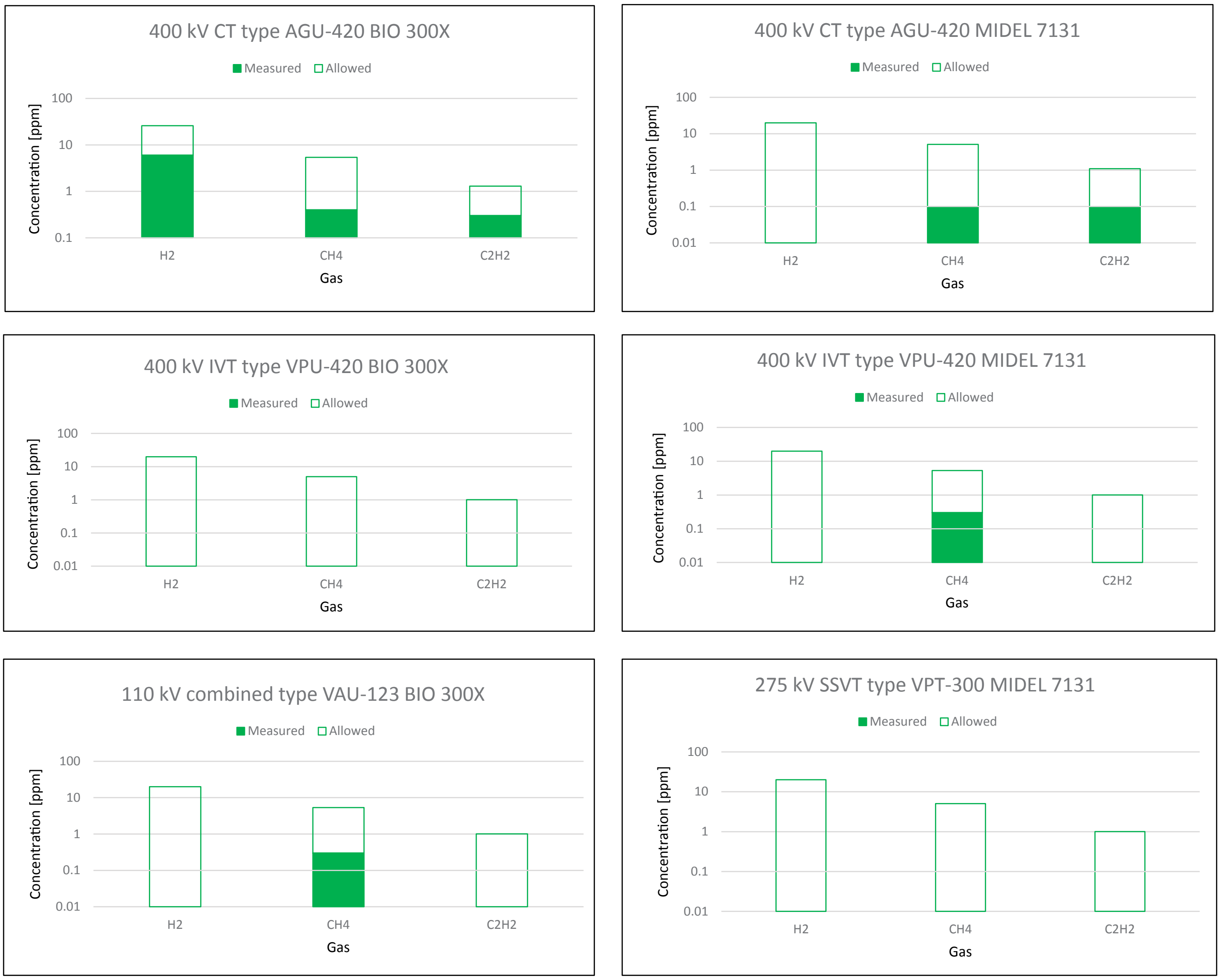

Figure 3. DGA results after multiple chopped impulse testing

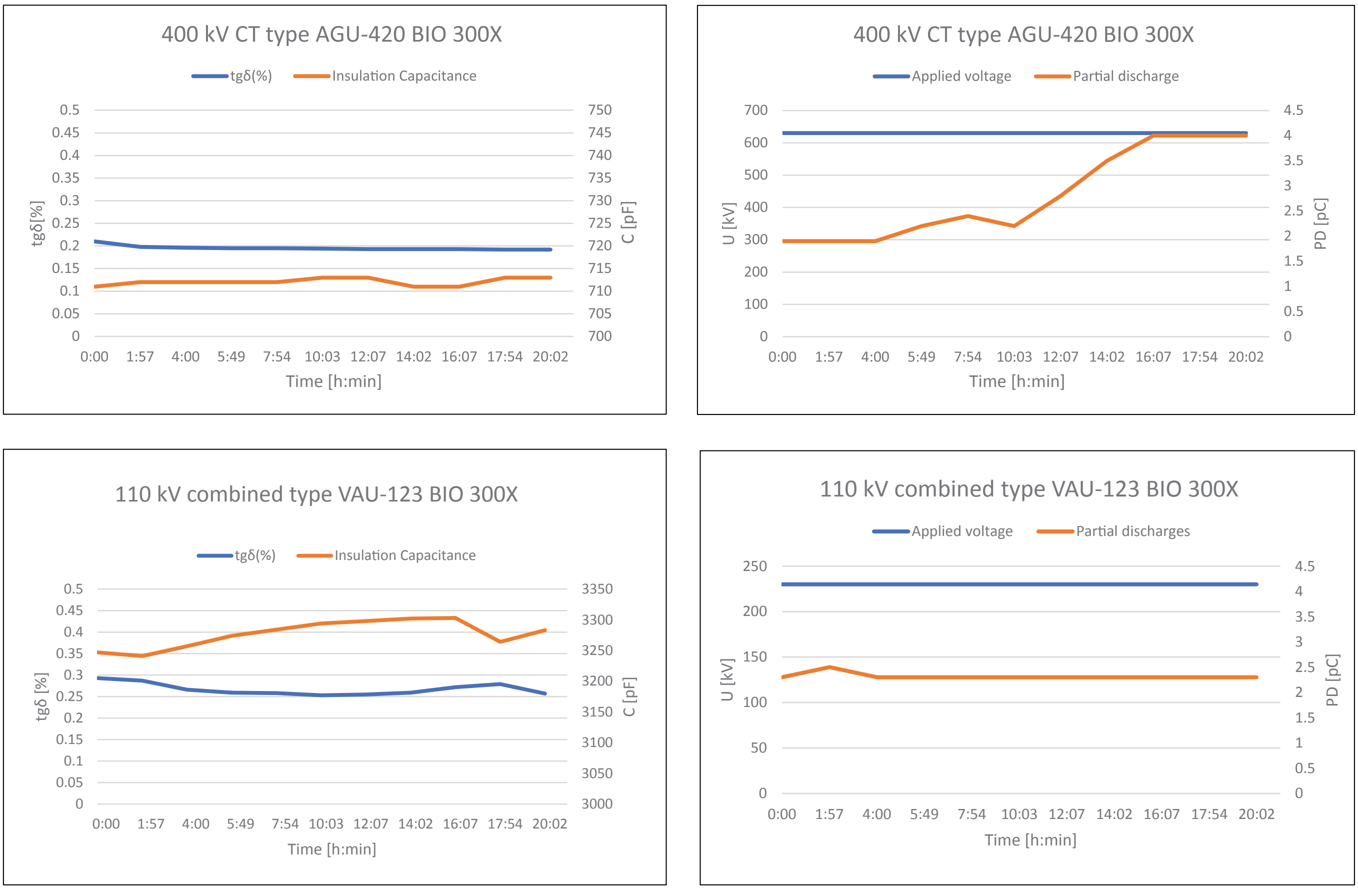

Figure 4. Tan delta, capacitance and partial discharges measurement during lifetime expectancy test

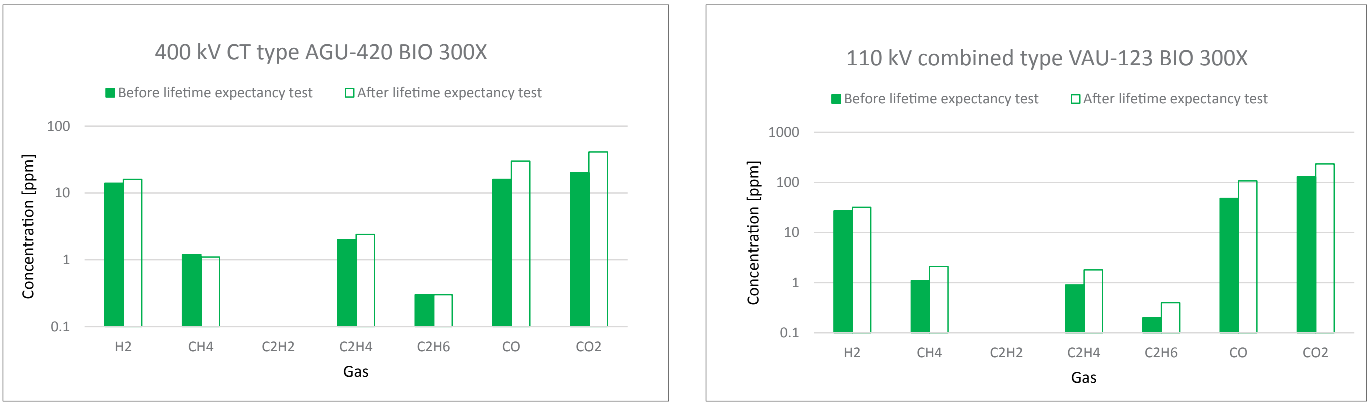

Figure 5. DGA results before and after the lifetime expectancy test

4.3 Lifetime expectancy test

The lifetime expectancy test is a proprietary non-standard test that was developed in cooperation with Končar Electrical engineering institute [3]. The purpose of the test is to simulate dielectric ageing during the transformer's lifetime. The instrument transformer is put on power-frequency withstand voltage for 20 to 24 hours (in contrast to the routine test where the duration is only 1 minute). This way, by extrapolating the procedure, 24 hours on power-frequency withstand voltage equal to roughly 40 years on maximum rated voltage. During the test, tg δ, capacitance and partial discharges are continuously measured.

Units filled with BIO 300X exhibited excellent performance, even better than conventional mineral oil. The measured results for tg δ, capacitance and partial discharges are shown in Fig. 4 while the gas rises (which were negligible) are shown in Fig. 5.

Units filled with MIDEL exhibited satisfactory performance but with a slightly higher tg δ value. This is to be expected since synthetic esters are known to have an increased value tg δ due to the polarity of the liquid.

4.4 Impulse until breakdown

The procedure for impulse testing until breakdown is as follows: the start of the test is at rated lightning impulse voltage. The voltage is then raised in steps of 5 %, with three positive and three negative impulses applied at each step. The transformer is tested until the voltage breakdown. An interesting unit regarding this test was a 400 kV CT filled with BIO 300X. The unit experienced dielectric breakdown at 1925 kV or 135 % of the rated lightning impulse voltage (1425 kV). Fig. 6 shows the voltage waveform of the breakdown while Fig 7. shows the DGA results before and after breakdown. These recorded values, which are practically identical for units filled with both BIO 300X and MIDEL, serve to prove that dielectric breakdown in these liquids results in a comparable gas increase footprint as conventional mineral oil.

5. Internal arc

An internal arc is a destructive test where an internal fault is simulated inside the head enclosure of the current transformer. Three 170 kV CT units with three different types of insulating liquids (mineral oil, MIDEL 7131 and BIO 300X) were tested. All three of them passed the test successfully, earning Internal arc class II (internal fault current r.m.s. value of 50 kA, arc duration 0.3 s), which is the best possible class regarding this test.

Internal arc class II for all three types of liquids has been achieved

Although the standard IEC 61869-1 is not quite conclusive on what constitutes a pressure relief device and what the term "fragmentation" actually implies (with burn-through and fire being acceptable) [5], the key is not to have any lateral projections of parts and only for the pressure relief device (which, in Končar design, is the bellows cover lid and bellows lid [6]) to detach itself in order for the energy release to be executed safely upwards.

All of the units behaved, basically, the same way with equivalent levels of released energy (around 6 MJ which is equivalent to the explosion of approximately 50 hand grenades). In Fig 8, all of the tested units are shown during the pressure relief operation.

As it is clear from Fig. 8, the insulating liquid doesn't have a considerable influence in the case of an internal arc. The reason for that is an extreme amount of energy released in a short time on a small oil volume held in non-expandable housing. This is why the design of the pressure relief system is the key to the successful completion of the test and the consequent operational safety that stems from internal arc qualification.

After extensive testing, Končar Instrument transformers considers both MIDEL 7131 and Nynas Nytro BIO 300X as fully implemented

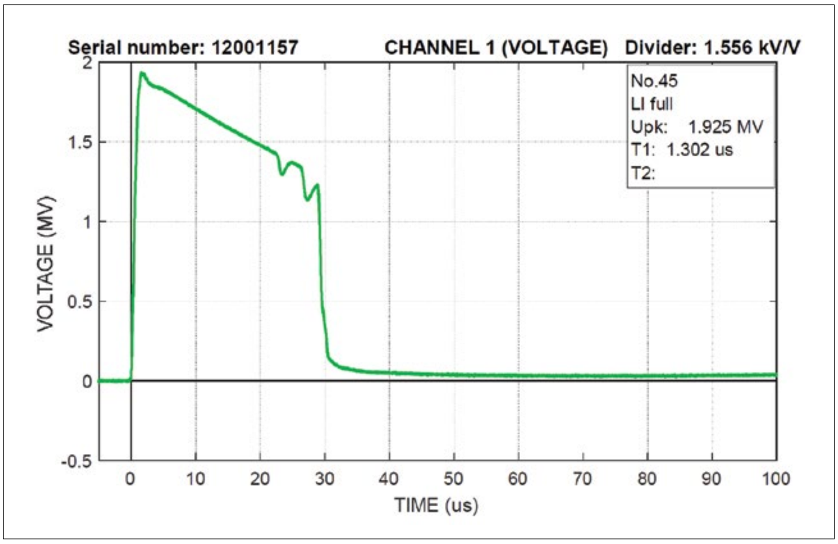

Figure 6. 45th lightning impulse waveform

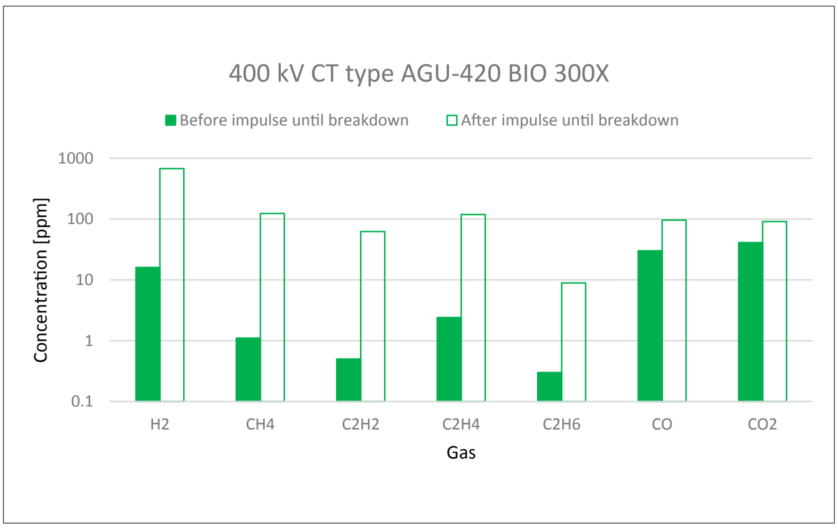

Figure 7. DGA results before and after impulse until breakdown test

6. Conclusion

After extensive testing, doing the additional homework and going beyond the scope of existing in verifying the design, Končar Instrument Transformers considers the implementation of both dielectrics to be complete. Commercial deliveries already started in Q1 of 2022 to various countries within the European Union, USA, and East Asia, to name a few. At this point, it is clear that an increasing number of customers understand and recognize the benefits of instrument transformers filled with biodegradable liquids.

It is Končar's outlook that biodegradable liquids are the future in which one wants to be, not only the pioneer but also the frontrunner. Therefore, in this task, it is essential to be impartial and objective, which is only possible by clearly understanding which liquid is the "best" and why.

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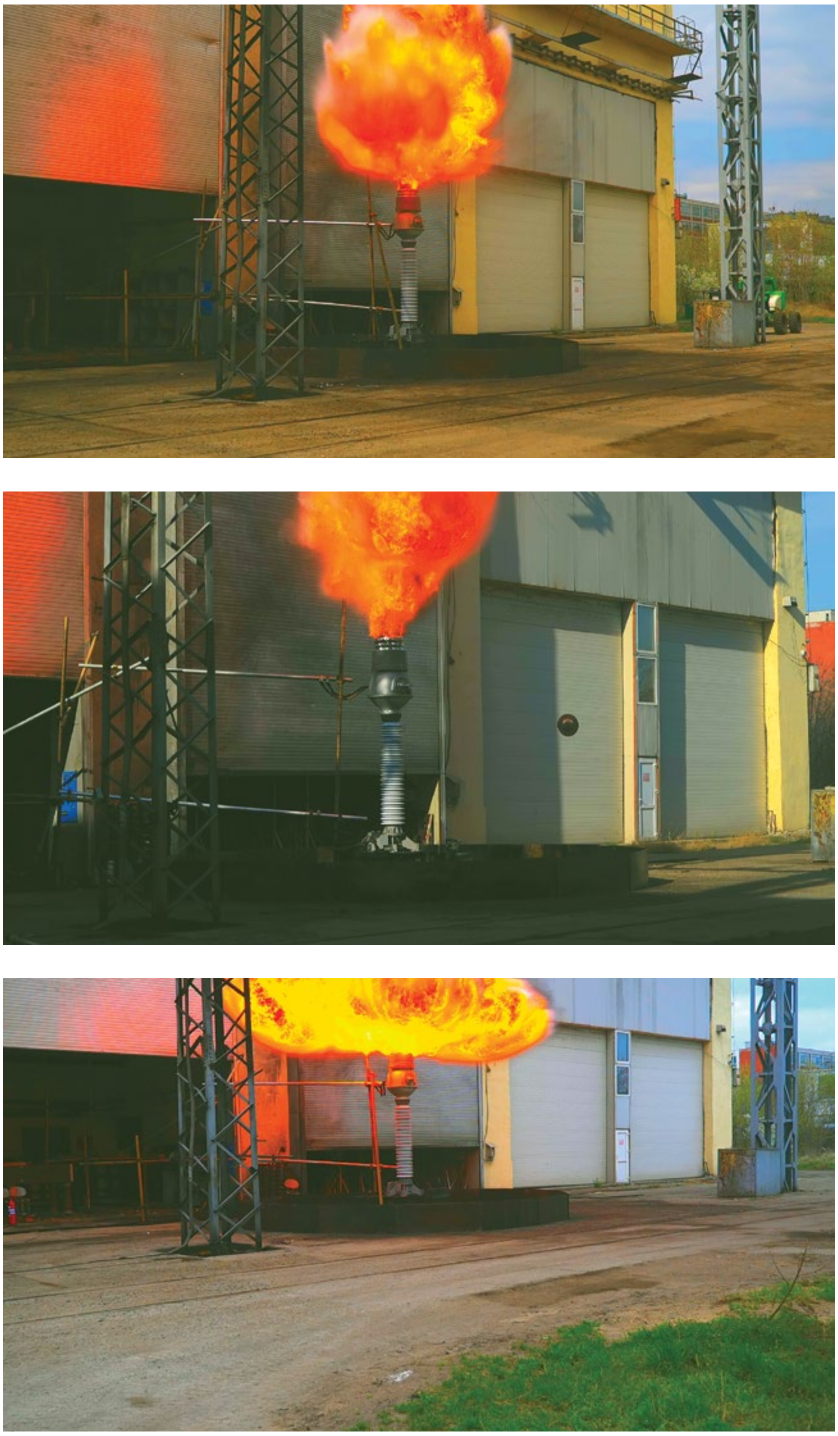

Figure 8. 170 kV CTs internal arc (from top to bottom: mineral oil, MIDEL 7131, BIO 300X filled unit)

Author

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