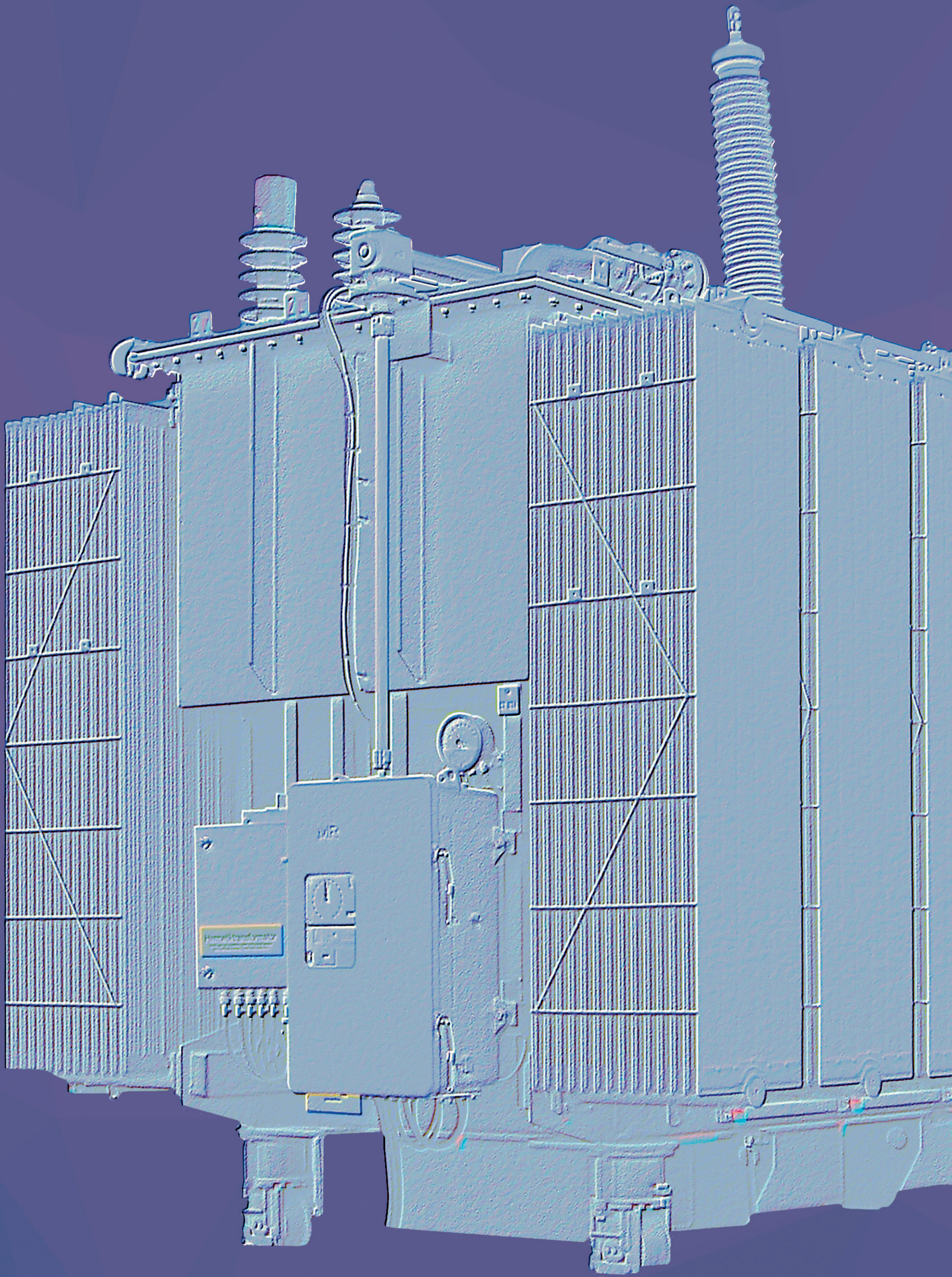

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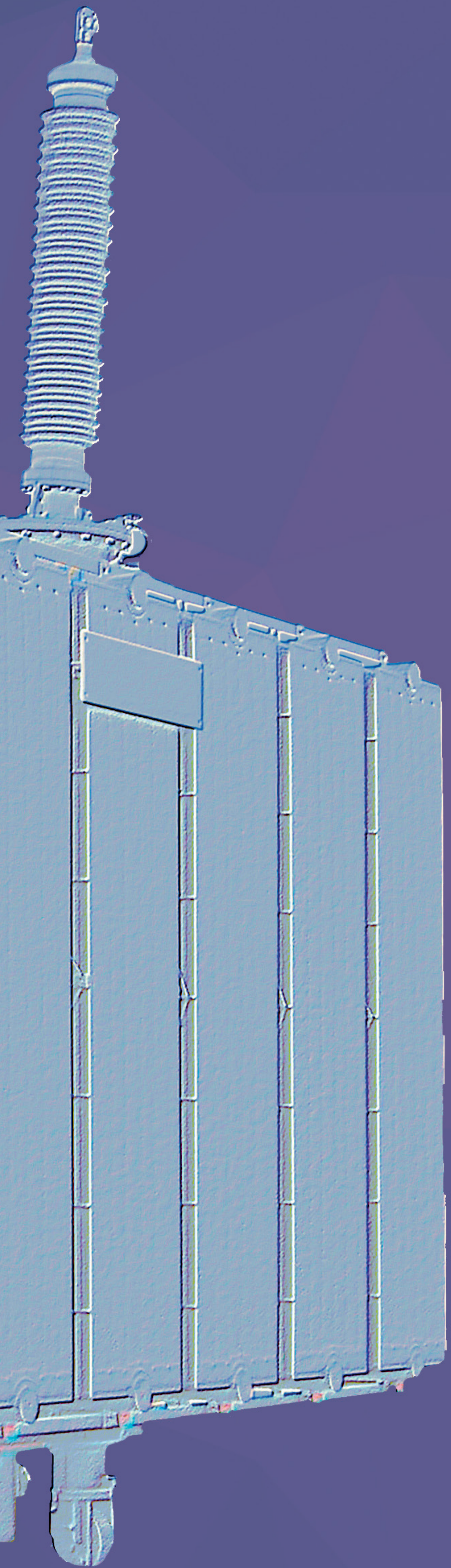
Every oil-filled electrical apparatus must be able to handle a certain thermal expansion of the oil, which is caused by varying oil temperatures due to load changes of the equipment and/or fluctuations in ambient temperature



Hermetical sealing of transformers and tap-changers

1. Introduction

Every oil-filled electrical equipment must be able to handle a certain thermal expansion of the oil, which is caused by varying oil temperatures due to load changes of the equipment and/or fluctuations in ambient temperature. With the coefficient of thermal expansion α_v estimated to $0.7 \cdot 10^{-3}$ 1/K, the oil volume varies for approximately 10 % within the standard operating temperature range between -25 to +115 °C. This volume fluctuation must be compensated by appropriate means. For transformers and on-load tap-changers (OLTCs), expansion tanks are commonly used, which are mounted typically with 0.5 to 5 m elevation above the tank or head cover, and so provide a light static overpressure. In special cases, elevations of 10 m and more are realized. Assuming an oil volume of 40,000 litres for a power transformer, the expansion tank must have a capacity of more than 4,000 litres. OLTC oil compartments contain between 125 and 1,000 litres of oil, so their expansion tanks must be designed for volumes between 16 and 190 litres. When both systems are filled with oil, it must be ensured that the expansion tanks do not overflow at maximum oil temperature and do not run dry at minimum oil temperature. The inside of the expansion tanks is usually connected to ambient air via dehumidifying cartridges (breather) to prevent the oil from collecting moisture from ambient. It is an essential requirement to avoid excessive moisture in insulating oil, as moisture lowers the dielectric strength of the oil and accelerates cellulose ageing. Dehumidifying cartridges contain a water absorbing granulate which must be exchanged or dried when saturated with moisture. Saturated granulate can easily be detected by a colour change, so regular control is necessary, in case no self-drying dehumidifying breather system is used.

The oil can be protected against direct contact with ambient air by applying sealing measures, which will be discussed in the following. With this, oxidative ageing processes of the oil and cellulose are extremely decelerated and moisture ingress is minimized. The oil is preserved, which reduces maintenance expenditures and enables higher loading without accelerating the ageing process. Standard-grade non-inhibited oils can be used as well as natural ester liquids, which are known as liquids with limited oxidation stability.

In the United States, over 90 % of all liquid-filled transformers are sealed, probably because sealed designs are preferred in the respective IEEE Standard C57.12.10 [1]. In the rest of the world, the majority of transformers are free-breathing, based on the recommendations given in IEC standard 60076-1, which describes free-breathing solutions first [2]. Bushings and instrument transformers are usually sealed and feature an internal gas space to handle the thermal oil expansion.

2. Sealing methods for transformers

a) The simplest method to prevent the oil from permanent contact with ambient air is to use a sealed-tank design, as shown in Fig. 1. While the active part of the transformer is fully immersed in oil, an air or gas blanket is provided underneath the tank cover. The volume of the gas blanket must be sufficient to allow a thermal oil expansion inside the tank without generating inadmissible overpressure. Bushings must be constructed in a way that they can bridge the gas blanket. If extreme temperature variations are expected, the sealed-tank design may prove impractical because of the large gas volume which is required to keep the system pressure within the admissible range. In case of an air cushion, the oxygen is slowly absorbed by the oil, leading to initial oil oxidation, and then stops once the oxygen is consumed. If this initial oil oxidation shall be avoided, nitrogen (N_2) can be used instead.

In case of an electrical fault, a large volume of free gases is generated. To avoid inadmissible overpressure and tank rupture, a pressure relief valve is provided to allow these fault gases to escape. But also during normal service, moderate amounts of thermally induced gases will be produced as dissolved gases. A portion of these gases will accumulate in the gas space in order to reach vapour pressure equilibrium between dissolved and free gases. So, over time, the initial air or gas blanket will change its composition.

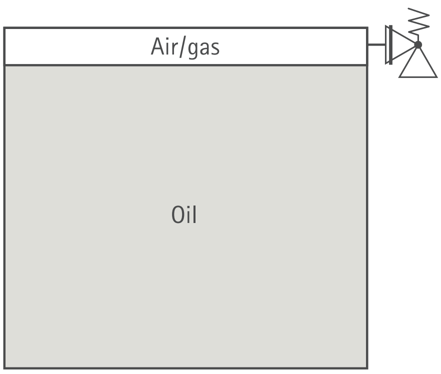


Figure 1. Sealed tank design

The main benefit of the sealed-tank design is its simplicity and its low maintenance requirements. For these reasons, sealed-tank designs are commonly applied to distribution transformers.

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A variant for sealed distribution transformers uses corrugated tank walls instead of a gas blanket. The crinkles allow a limited alteration of the tank volume and so can also compensate for the thermal oil expansion.

b) The pressure inside a sealed tank using a gas blanket can be controlled by using a nitrogen preservation system; see Fig. 2. It uses a pressurized nitrogen bottle with a pressure regulator and a breather to maintain a predefined positive pressure range in the tank. The desired pressure range can be set by the user. The system adds nitrogen, if necessary, or vents overpressure to the atmosphere automatically. An alarm is set when the nitrogen bottle is empty [3]. In case of excessive temperature cycles or gas leaks, the nitrogen bottle will require frequent replacement, which renders this solution as not maintenance-free.

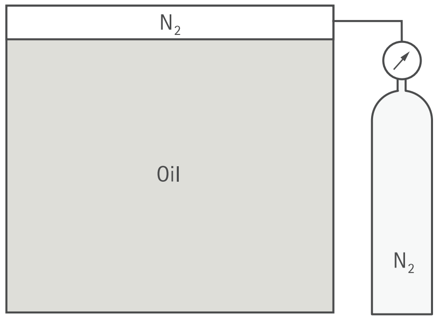

Figure 2. Sealed tank design with nitrogen preservation system

c) Not maintenance-free is also the solution which uses an expandable rubber bag, bladder, membrane or diaphragm in the oil expansion tank; see Fig. 3. The inside of the bag is connected to ambient air via a dehydrating breather. Like in free-breathing systems, the efficiency of the dehumidifying cartridge must be controlled, and the lifetime of the rubber bag is also limited. Over the years, rubber may get porous and so will eventually allow the ingress of oxygen.

There is some discussion if this solution can be regarded as "hermetically sealed", as it does not represent a closed pressurized system and the rubber allows a limited transfer of gas molecules (e.g. hydrogen). But in contrast to open systems, free gases which may develop in case of a failure, will not be able to escape sufficiently fast to prevent the system from inadmissible overpressure. In this spirit, the system must be regarded as "closed" or "sealed".

d) If the air inside the rubber bag is replaced by an inert gas, e.g. N_2, the system becomes maintenance-free. To avoid large variations in pressure, the rubber bag is connected to a voluminous N_2 storage tank (compression tank) which can be mounted remotely from the transformer (Fig. 4). With this, the gas temperature is sufficiently decoupled from the oil temperature, which minimizes pressure variation. Over the full

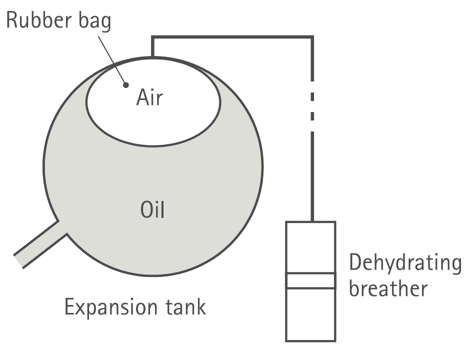

Figure 3. Expansion tank with rubber bag

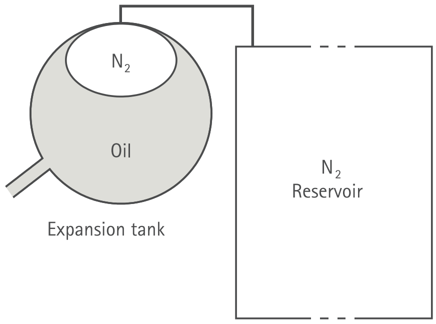

Figure 4. Expansion tank with rubber bag and N_2 storage tank

standard oil temperature range of -25 to +115 °C, the system is always operated under light overpressure. No breather is necessary because it is a closed system, and it enables full Buchholz protection and further benefits [4]. Due to the absence of oxygen, ageing of the rubber is also minimized.

As a variant, the rubber bag can be omitted so that the N_2 cushion is in direct contact with the oil in the expansion tank.

e) A different approach uses expanding radiators to accommodate the thermal oil expansion (Fig. 5).

By using a special welding procedure the radiators are capable of taking over both the cooling function as well as the function of thermal oil expansion without loss in mechanical stability. The varying space between the radiator ribs does not impede air flow which is necessary for cooling. With this, the expansion tank and any air or gas cushion is omitted. This significantly simplifies the construction of the transformer tank and allows a higher flexibility for the position of bushings etc. on the transformer top. Long-time stability of the expanding radiators has been proven in various field applications [5].

These methods are the most common solutions applied in the field. Further methods and derivatives of the pictured methods are available, but they are applied only when circumstances enforce such solution.

3. Applicability to tap-changers

Basically, all sealing solutions described above are also applicable to OLTCs, depending on the particular model. In case of conventional (oil switching) type tap-changers, huge amounts of carbon, soot and gases are produced by the switching arcs. In case of hermetical sealing, a venting valve must be applied to release these gases. Otherwise, the gases would quickly cause inadmissible overpressure in the system. Several commercially available solutions for venting valves have been evaluated and discarded. The major problem was the deficient compatibility with hot insulating oil and the quick plugging by carbon particles. During an R&D project, a floating valve with some clever features was designed which proved a principal feasibility, but it never matured in a concrete product. Without a venting valve, oil switching OLTCs cannot be sealed. Sealing is also not reasonable in this case, as the main motivation for applying sealing methods is the reduction of oil ageing, prolongation of maintenance intervals, etc. These benefits do not count for oil switching OLTC models because arcing in oil is the dominating process. And this enforces regular maintenance, i.e. replacing the oil, clean the oil compartment and restore worn contacts.

Tap-changers with vacuum switching technology use vacuum contact chambers for making and breaking the load current. These vacuum interrupters fully encapsulate the switching arcs so that the diverter switch oil is no longer carbonized. A high quality of the tap-changer oil is maintained over the whole lifetime so that it doesn't have to be replaced regularly anymore. The conditions for the oil are similar to the conditions in the transformer. Vacuum technology in OLTCs has been applied now for over 30 years and has definitely proven its reliability. It offers strong benefits which pave the way for further innovations:

- The extremely long contact life of vacuum interrupters leads to maintenance intervals of 300,000 or 600,000 operations, depending on the respective OLTC model. For standard applications in power supply networks with 5,000 to 10,000 switching operations per year, this means that the tap-changer mechanism is free of maintenance for the whole transformer life of 30 years and more.

- Vacuum type OLTCs do not produce free gases during normal service. This has been proven by power switching tests which were performed on all VACUTAP® models under full load and overload conditions. Further tests on transition resistors in model setups have shown that free gases are produced only in thermally aged and air-saturated mineral oil, when the transition resistors heat up for more than 350 K. In sealed applications, the oil should not reach these states, because

  1. the oil is normally filled in under vacuum and so should be sufficiently degassed; and

  2. the missing contact to ambient air impedes oxidative oil ageing.

  Free gases should be avoided, because gas bubbles may impair dielectric insulation. So, as an additional measure, a special design for the transition resistors is provided to ensure a temperature rise of less than 300 K, even when switching through the whole regulating range with 1.5 times overload.

- Low amounts of dissolved gases are produced during normal service. This enables DGA to be an appropriate method to monitor the "health" condition of the OLTC, in the same way as it is commonly applied to transformers. DGA for OLTCs will be discussed in future columns here in Transformers Magazine.

- Persisting high oil quality and low amounts of dissolved gases also enable the combination of tap-changer oil and transformer oil. A strict separation of the two oil volumes is no longer necessary. This topic will be reviewed in the next issue of Transformers Magazine.

Solutions a) and b) cannot be applied to in-tank type models, as *the OLTC compartment must always be filled completely with oil.* Beneath the OLTC head

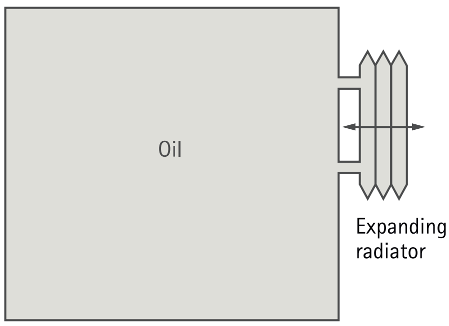

Figure 5. Expanding radiator

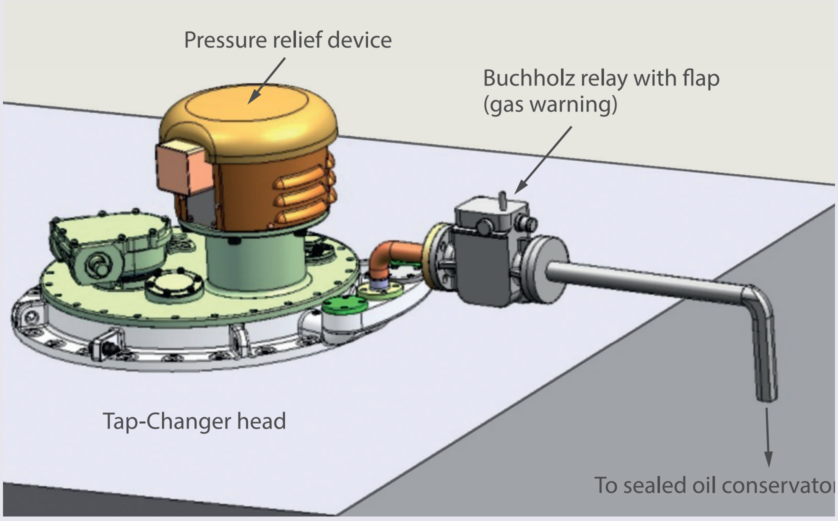

Figure 6. OLTC protection concept for sealed applications

Sealing of oil switching OLTC models is not beneficial because arcing in oil is the dominating process

cover, the energy accumulator and geneva gear may not run dry, and below that assembly, the phase-to-ground insulating distance is designed to perform in insulating liquid. With this, in-tank type OLTCs always need an expansion tank, no matter how it looks like. Sealing measures c) to e) can be applied without any impact on the performance of the tap-changer. Solutions a) and b) are only applicable for compartment type OLTCs, as they are commonly used in the U.S. and U.K. These tap-changer models need a gas space above oil level, because they usually don't feature a separate expansion tank.

4. Protection concept for sealed tap-changers

Even if hermetical sealing does not affect tap-changer performance, the protection concept must be rethought. According to IEC 60214-1, the tap-changer manufacturer is in duty to supply a protective device in order to minimize the risk of fire or explosion which can result from an internal failure within the diverter or selector switch compartment. For in-tank type OLTCs in free-breathing applications, an oil-flow relay which is mounted in the pipe leading to the expansion tank acts as protective device and triggers the circuit breaker in case of a failure inside the tap-changer oil compartment. For compartment type OLTCs, a pressure relief device (PRD) performs the same task.

In sealed tap-changers, the reliable operation of the oil flow relay cannot be guaranteed, because the sealed expansion tank may impede oil flow. The tap-changer manufacturer often does not even know which sealing method is applied! A suitable device, which operates regardless of the applied sealing solution and independently of pipe geometries, is the PRD (Fig. 6). The PRD guarantees extremely responsive, effective protection of the OLTC which always triggers under the same, precisely defined conditions. The tripping characteristic of a PRD is different to that of an oil flow relay, as shown in Fig. 7. Incipient failures may show a slow increase in pressure by producing gas bubbles which cannot be detected by the PRD. To detect such irregularities, a Buchholz relay is additionally mounted along the pipe to the expansion tank. It should not trip the circuit breaker, but only produces a warning signal if free gases are collected. The obligatory flap of said Buchholz relay can be additionally used to detect unusual oil flow. It can be wired as optional protection to support the PRD.

5. Summary

To successfully run an on-load tap-changer in a sealed (closed) environment, three things are necessary:

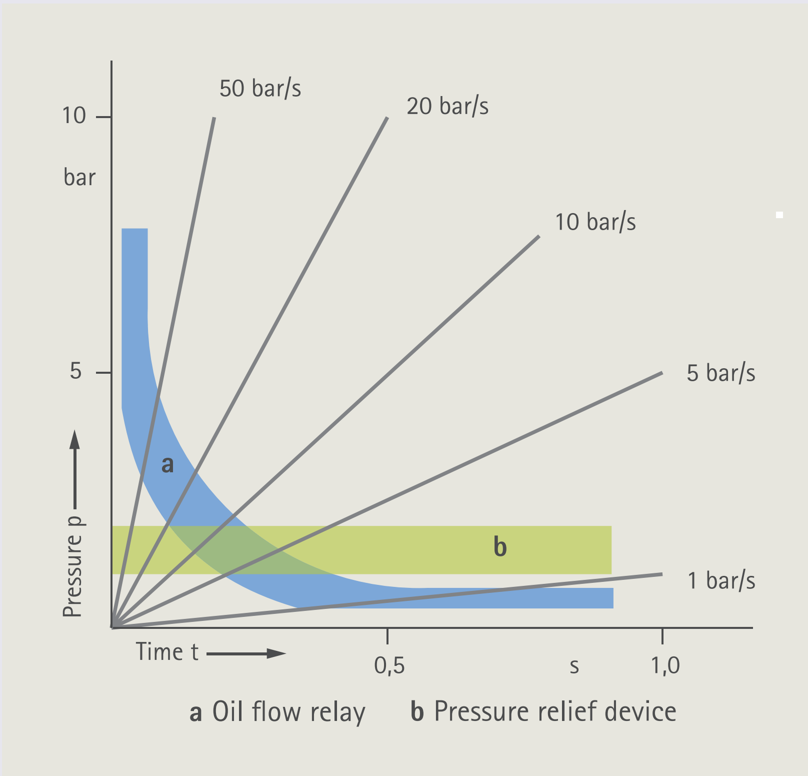

Figure 7. Response characteristics of protective devices

1. a vacuum type OLTC
2. an appropriate sealing solution, and
3. an adequate protection concept for the OLTC

Sealed OLTC applications can be designed as maintenance-free, and they are ready to be used with natural ester liquids (see Transformers Magazine, Vol 3, Issue 3).

Literature

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[2] IEC 60076-1, *Power Transformers – Part 1: General*

[3] ABB, *Inertaire® Oil Preservation Systems – Installation, Operation and Maintenance Guide*, document number IZUA 7633-210en

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A suitable protective device, which operates regardless of the applied sealing solution and independently of pipe geometries, is the pressure relief device

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