For many applications, there is no technical reason anymore to keep the oil volumes of a transformer with vacuum type OLTC separated

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Photo courtesy of Siemens

Common oil expansion tank for transformers and tap-changers

1. Introduction

On-load tap-changers (OLTCs) feature an own oil compartment which accommodates the diverter switch or selector switch and separates the tap-changer oil from the transformer oil. This strict separation is necessary for conventional diverter and selector switches, because the arc-breaking operation deteriorates the oil in the tap-changer compartment severely and produces huge amounts of particles, soot and gases. It must be ensured that these deterioration products do not contaminate the transformer oil. For this reason, the active IEC and IEEE tap-changer standards [1], [2] require a tightness test or container integrity test for the diverter switch or selector switch.

This test is only passed if the tap-changer oil compartment is pressure tight and gas tight. Nevertheless, there is a huge number of older units installed in the field which may show some leakage. This does not mean that the tap-changer oil mixes with the transformer oil to a big extent, but at least dissolved gases are able to travel between the two oil volumes and so may influence transformer DGA. There are basically three pathways which are used by tap-changer gases to diffuse into the transformer oil: via a non gas tight oil compartment (as seen for some old press paper cylinders), via leaking gaskets, or via a common air space in the oil expansion tank; see Figure 1. The latter case is often not considered, but it appears quite often, e.g. in Eastern Europe. Dissolved tap-changer gases outgas to the air space in the expansion tank and dissolve again in the transformer oil, depending on the ruling gradients in partial pressure. With respect to such cases, IEC60599 specifies higher values for acetylene in the transformer oil (for typical gas concentration rates and typical rates of gas increase) for so-called "communicating OLTCs" [3].

Modern OLTC models use vacuum interrupters which encapsulate the switching arcs and so prevent the oil from pyrolytic degradation. Carbon particles are no more produced, only some sparks of low energy occur, due to some current commutation between the OLTC-internal current paths during the switching process. These sparks only produce very low amounts of sparking or arcing gases. Inside the transformer, capacitive switching arcs of low energy must be broken when the change-over selector is operated. They produce low amounts of arcing or sparking gases which, in the majority of cases, are not visible in the transformer DGA. The ageing impact of both arcing/sparking processes on the oil is negligible. As a result, the OLTC oil is only thermally aged by the heating of transition resistors. Their thermal impact roughly corresponds to the impact of waste heat from the transformer windings on the transformer oil. So, it can be stated that the stresses on OLTC (vacuum type) and transformer oil are very similar; they cause similar compositions and amounts of dissolved gases and so allow an exemption from the above mentioned tightness or container integrity test.

To put it in a nutshell: if vacuum type tap-changers are used, the conditions for the tap-changer oil are very similar to the conditions for the transformer oil. For many applications, there is no technical reason anymore to keep the two oil volumes separated. So, what prevents us from joining the two oil expansion tanks (and so the oil volumes)? It simplifies oil handling and offers savings.

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2. Gas exchange between connected oil volumes

Connected oil volumes are only reasonably applied to in-tank type OLTCs. Compartment type OLTCs usually don't feature an oil expansion tank because they compensate the thermal oil expansion by using a gas space underneath the tank cover (see [6], page 26, Figure 1). They are not completely filled with oil, so the connection with the transformer oil does not offer concrete benefits.

In-tank type OLTCs must always be completely filled with oil to ensure that the drive mechanism and the phase-to-ground insulating distance are covered with oil. This requires a separate expansion tank for the OLTC oil, often called conservator, to compensate for the thermal volume dilatation. This conservator can be omitted if there is a permanent connection between tap-changer oil and transformer oil. Now, it would be interesting to know how the oils intermix. Be it that a failure develops inside the tap-changer, dissolved gases will differ more or less significantly from the gases in the transformer. With a permanent connection, they can be introduced in the transformer oil and may influence transformer DGA.

To investigate the dimension of liquid and gas exchange, a test has been performed, using a model setup with two oil compartments. A small tank (65 litres, "tap-changer") was mounted in a bigger tank (1185 litres, "transformer"). Both oil volumes were interconnected by a pipe elbow (see Fig. 2) and filled with degassed mineral oil. The "tap-changer" oil was then inoculated with 150 ppm C_2H_2. The resistor inside the "tap-changer" compartment was heated by current impulses which were controlled by an electronic AC power supply. The current impulses simulated the switching operations and caused well-defined fast temperature rises, representing the typical resistor heating of a tap-changer under network load (ΔT 160 K) and under 1.5 times overload (ΔT 250 K). 300,000 current impulses were applied in total. The maximum oil temperature in both oil compartments was limited to 50

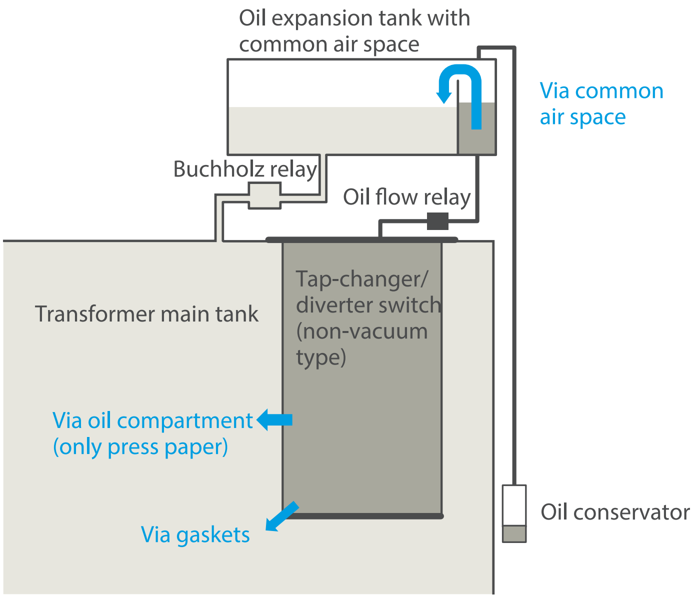

Figure 1. Different pathways for gas contamination of the transformer oil by OLTC gases

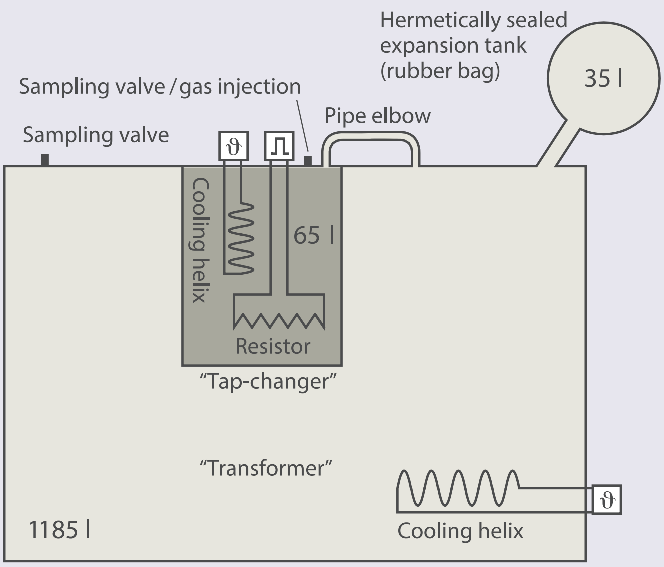

Figure 2. Test setup for gas exchange with connected oil volumes

°C by cooling helixes to minimize a potential self-gassing activity of the oil.

The heat energy introduced by the resistor heated the "tap-changer" oil and so caused a thermal expansion. With each impulse, the "tap-changer" oil volume expanded for approximately 1 ml. A temperature rise of 25 K (difference between ambient temperature 25 °C and maximum oil temperature 50 °C) caused a volume increase of approximately 1.2 l. This amount of oil moved through the pipe elbow into the transformer during the heating period and was drawn back during the cooling period. In total, 17 heating/cooling cycles within one-month time were performed, causing a permanent oscillation of 1.2 l of oil, the total transported oil volume summed up to round about 20 l.

Regular oil samples were taken from both oil compartments and DGAs were performed. After the test, the "tap-changer" oil showed a slight increase of the heating gases CH_4, C_2H_4, C_3H_8 and C_3H_6, between 1 and 7 ppm for each gas. In the transformer oil, the increase of dissolved heating gases was below 1 ppm and no C_2H_2 was detected.

It can be assumed that the transported oil volume did not fully exchange with every cycle, which means that transformer oil and tap-changer oil keep rather separate, as long as a 1" pipe or a similar connection with small cross section is used. For a network transformer, the oil expansion of the OLTC oil which is caused by resistor heating and daily temperature cycles of the transformer is quite low. Diffusion processes of dissolved gases through small cross sections are very slow and can be neglected.

In the theoretic case of a complete intermixing of "tap-changer" oil and "transformer" oil, 150 ppm C_2H_2 in the "tap-changer" oil would dilute to about 8 ppm C_2H_2 in the "transformer" oil ($150 \cdot {}^{65}/_{1185}$ ppm). For real applications, the ratio of oil volumes is much bigger than in the test (about 1:100). Furthermore, 150 ppm C_2H_2 should not occur in a vacuum type tap-changer in regular service. Such high C_2H_2 amount clearly indicates a malfunction.

As a conclusion, it can be stated that it is very unlikely to disturb transformer DGA by OLTC gases, as long as the cross section of the connection is small. Several pilot applications and field studies [4], [5] have verified this.

3. Implementations of connected oil volumes

The realized applications use different solutions to connect the oil volumes of tap-changer and transformer. They can be applied to free-breathing applications as well as to sealed applications. Sealing of (vacuum type) tap-changers was discussed in [6].

Figure 3 shows a possible solution for free-breathing applications. The pipe from the tap-changer compartment, which normally leads to the OLTC expansion tank, is connected directly to the pipe which leads from the transformer to the expansion tank. With this, the separate chamber in the expansion tank for the OLTC can be omitted, including its oil level indicator and dehumidifying cartridge. It has to be considered that, in case of a beginning failure inside the transformer or OLTC,

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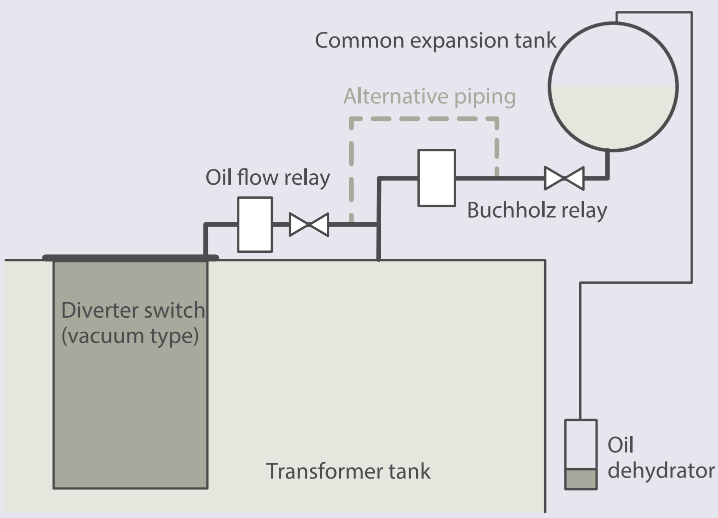

Figure 3. Connected oil volumes for free-breathing applications

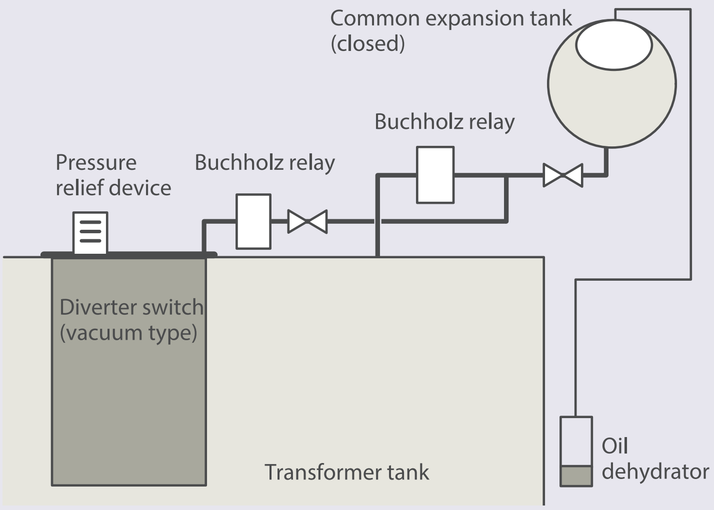

Figure 4. Connected oil volumes for sealed applications; principal schematic

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the fault gases cannot be explicitly assigned to the transformer or the OLTC. If this is a problem, an alternative piping can be used which connects the OLTC pipe to the expansion tank *behind* the Buchholz relay (see Fig. 3). This also minimizes a possible gas exchange between the two oil volumes.

Concerning sealed applications, the applied sealing method is often unknown to the tap-changer manufacturer, so the proper function of the oil-flow relay cannot be guaranteed. If the OLTC protection concept for sealed tap-changers, see [6], is applied in combination with the piping shown in Figure 3, the solution according to Figure 4 is achieved. The concept provides a Pressure Relief Device (PRD, mandatory) and a Buchholz relay as gas warning device (optional). If a separate tap-changer gas warning is not required, the Buchholz relay of the transformer can adopt this function (see Fig. 5). It has to be pointed out that, in this case, the origin of possible free gases cannot be located. Anyhow, the OLTC protection concept for sealed applications is fully supported.

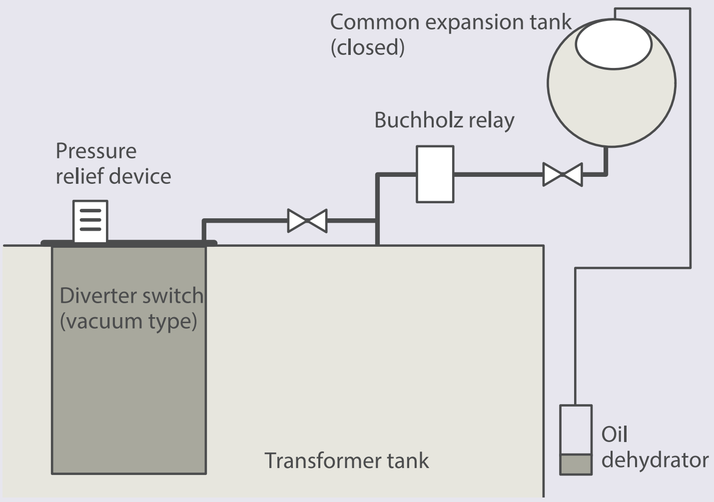

Figure 5. Connected oil volumes for sealed applications; optimized solution

All these solutions can be found in the field and they are working reliably.

4. Minimized piping

Figure 5 represents an optimized implementation which fully supports the protection concept for sealed tap-changers. Several years of field experience have shown that vacuum type tap-changers do not produce any free gases during normal service. Courageous users may now go without the OLTC gas warning, as it is just optional, and not a requirement. The shortest possible connection between the two oil volumes is a connection between the two pipe flanges "E2 and "Q" (see Fig. 6) on the OLTC head. "E2" opens out into the transformer tank; "Q" ends in the OLTC compartment. The connection can be realized by a metal plate *("connecting bone"*, named after its shape), which features a through-hole between the two pipe flanges. The pipe flanges are both closed by blind covers. The connection can be closed by a valve screw with two gaskets (see Fig. 7), in case the OLTC must be opened for inspection or maintenance. The valve screw must always be open during normal operation to allow a compensation of thermal oil expansion into the transformer tank. The connecting plate can be applied to free-breathing and sealed applications in the same way. Note that, with open connection, the oil pressure inside the OLTC always exactly equals the pressure inside the transformer tank, which is determined by the height of the oil expansion tank (free-breathing) or the preset system pressure (sealed).
Diffusion processes of dissolved gases between the two oil volumes will be very low and thus are negligible, due to the small diameter of the through-hole in this example.

As there is no pipe leading from the OLTC to an oil expansion tank (or the transformer tank), the standard oil-flow relay cannot be applied anymore as protective device for the OLTC. As a substitute, a PRD must be applied, like in the protection concept for hermetically sealed OLTCs. The PRD triggers the circuit breaker in case of an internal flashover or severe malfunction of the tap-changer mechanism. This is necessary because a sudden rise in pressure cannot be broken down fast enough by the oil flow through the thin via in the connecting plate.

> **The most simple, easy-to-apply and cost-effective solution is achieved by using the *connecting bone***

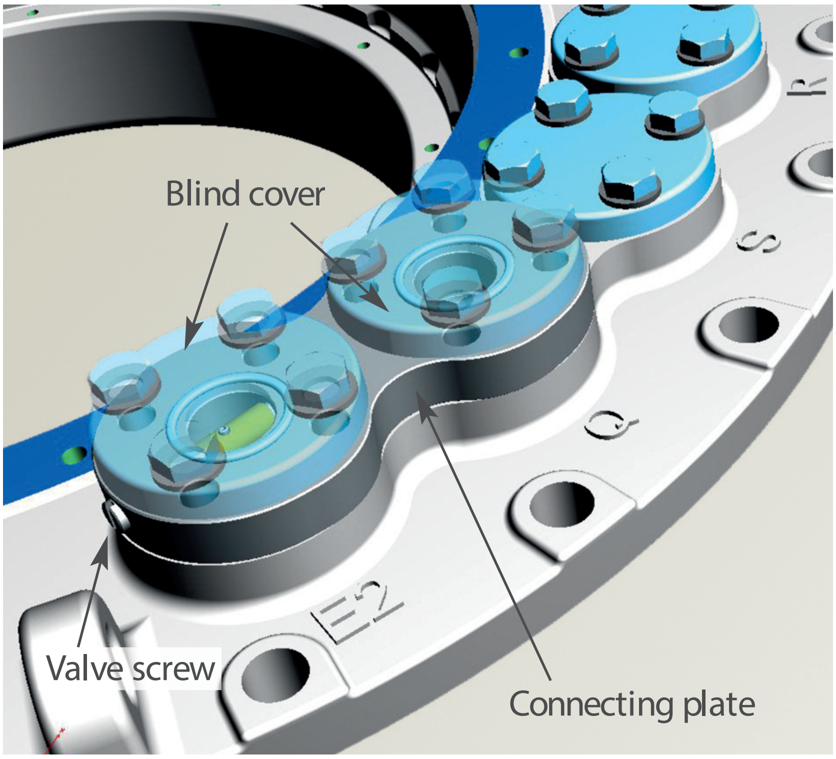

Figure 6. Connecting plate on OLTC head cover for connecting the oil volumes of transformer and vacuum type tap-changer

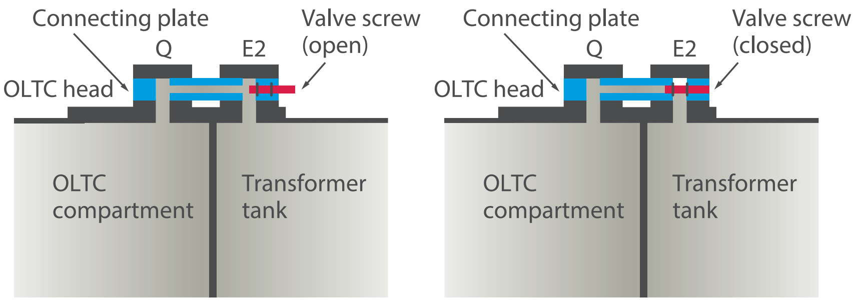

Figure 7. Connected oil volumes with connecting plate (section)

Conclusion

The connection of oil volumes of transformer and tap-changer offers several advantages and savings, such as a simplified piping construction and the omission of a second oil conservator. There are different solutions available, depending on the construction of the transformer oil expansion unit. This can be a rubber bag, a nitrogen reservoir or an expanding radiator. The most simple, easy-to-apply and cost-effective solution is achieved by using the *connecting bone.* Note that all solutions for combined oil volumes shall only be applied to vacuum type tap-changers. Even if it is not really necessary, the tap-changer oil compartments will still be manufactured pressure tight and gas tight, no matter how the connection is executed.

5. Literature

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