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Using Perfluorocarbon Tracers (PFT) for detecting oil leakages in LPOF cable systems

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SUMMARY

HV and EHV XLPE insulated cable systems are widely installed nowadays but the backbones of most transmission grids are Fluid-filled cable systems. The high performance of these Fluid-filled systems is guaranteed for decades under the condition that the hydraulic system is intact: leakages, even small ones, may shorten the life-time of such cables (systems) and can have a negative impact on the environment.

PFT (PerFluorocarbon Tracers) technology is added to the cable fluid in minimal quantities and where the cable system is damaged, the fluid with the volatile PFT compounds permeate through the ground and can be detected using highly sophisticated detection equipment. The advantages of PFT detection are that small leakages can be found, the environmental impact is reduced, detection when circuit is in service and single excavation to repair the leak.

The PFT compatibility with HV LPOF cable systems is underlined by a successful type test, in full accordance with IEC60141, and a pilot project where a small oil leak (18 liter per week) was detected at 6m depth, underneath railroad tracks.

KEYWORDS
LPOF, end of life time, NO_2 freezing, fatigue, PerFluorocarbon Tracers, PFT, environmental

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1 - INTRODUCTION

Around the world the backbone of underground electricity transmission has been borne by fluid filled cables generally operating between 33kV and 400kV, some of which are still in service since the 1930’s [1]. Fluid filled technology has largely been superseded by XLPE type cables. However, most utilities and transmission operators have significant quantities of fluid filled systems within their networks and will continue to do so for many years [2].

Fluid filled cables have proven to be reliable, provided the fluid pressure is maintained via the integrity of the metallic sheath and associated accessories. Leaks can occur on fluid filled cables for a number of reasons but typically through metal fatigue, external corrosion or third party damage. Once a leak occurs it is generally identified by the cable operator through the activation of low pressure alarms and to ensure that the cable remains operational new cable fluid is pumped into the system pressure tanks to keep pace with the leak volume.

Traditionally the main method for locating cable fluid leaks has involved de-energizing of the cable circuit, excavation to gain access and then applying a liquid nitrogen freeze (photo 1).

Photo 1 ‘freezing of 36/50kV fluid filled cable in urban area’

photo 2 ‘Equipment for injecting PFT in LPOF system during service’

Fluid pressures are monitored to determine on which side of the freeze the leak is occurring. This process is then repeated at different locations until the leak is found. It is not uncommon for this process to take between 3 & 7 attempts before the leak is located. Many old lead sheath cables have porosity and the cable leaks when high loadings are applied. When the circuit is de-energized and the temperature decreases, the leaks often close up making them difficult to find.

2 – PFT TECHNIQUE

Perfluorocarbon tracers (PFT) are highly volatile compounds, with excellent electrical insulation properties which are added to the cable fluid in minute quantities. If the cable system is damaged, the fluid with the volatile PFT compounds permeates through the ground and can be detected using highly sophisticated detection equipment [3]. The advantages of this system are:

- small leakages, < 5 liter/day, can be found,
- reduction environmental impact,
- detection is possible with cable circuit in service,
- extend the cable circuit life time,
- only single excavation is needed to repair oil leakages

Injection methods
For now there are two methods of injection available, being the “full flush” method and the “PFT injection during service” (photo 2). When the “full-flush” method is applied, the cable circuit is de-energized and the pressure tanks are closed. The free cable fluid is then flushed with PFT cable fluid. This is the quickest way to tag a cable circuit. With the “PFT injection during service” method a cable circuit is injected with an extra high concentration of PFT cable fluid during routine maintenance. This method can take a number of injection’s before the PFT Tracers reach the cable leak depending on the location of the leak in relation to the distance from the injection valve and the leak rate. A new, more efficient, method for injecting PFT cable fluid is under development in cooperation with one of the largest utilities of the Netherlands “Alliander”, see chapter 4.

Detection
Perfluorocarbons are a man-made substance which are present in the atmosphere at very low background levels, typically 2-3 parts per quadrillion (ppq). An advanced mobile laboratory (photo 3) has developed which can detect the background levels of perfluorocarbon in the atmosphere.

Photo 3 ‘PFT mobile laboratory for detecting small quantities of PFT in the atmosphere’

Upon arrival at site the air over the cable route is sampled (when possible) by driving along the cable route or by handheld sampler. Any PFT which has permeated through the subsoil from the leaking cable fluid will be detected. When a high level of PFT is identified by the PFT van, a handheld sampler is used to pin point the location within one-two metres of the cable leak.

3 – LABORATORY TESTS

In order to demonstrate the compatibility of PFT with HV LPOF cable system technology, a type test at 87/150kV level was initiated. For this, 30 m of 87/150kV fluid filled cable, with 800 mm^2 Cu conductor and lead sheath, was installed with one 180^o bend and terminated into porcelain outdoor terminations. The tested cable was produced and installed in 1969 and was in service for almost 40 years.

Before the type test was started, the test loop was injected with PFT and measures were taken to ensure the PFT had impregnated the cable main insulation. An adaptor was installed on one of the terminations which made it possible to inject the PFT directly into the oil channel of the cable (figure 1).

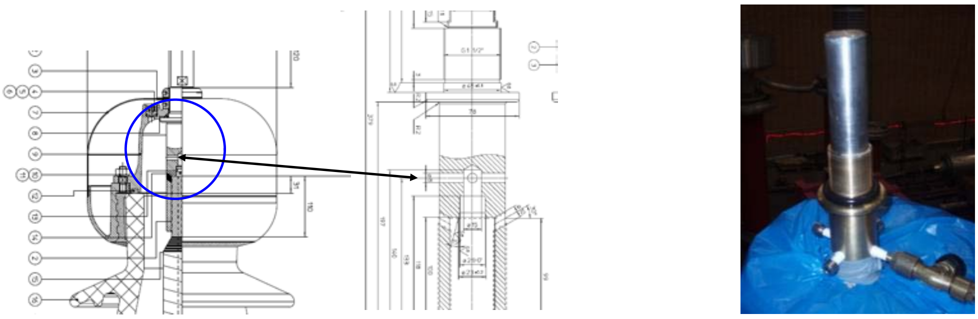

Figure 1 'Detail of termination modification in order to inject oil with PFT concentrate directly into the cable oil channel'

Photo 4 '87/150kV LPOF cable injected with PFT type test loop'

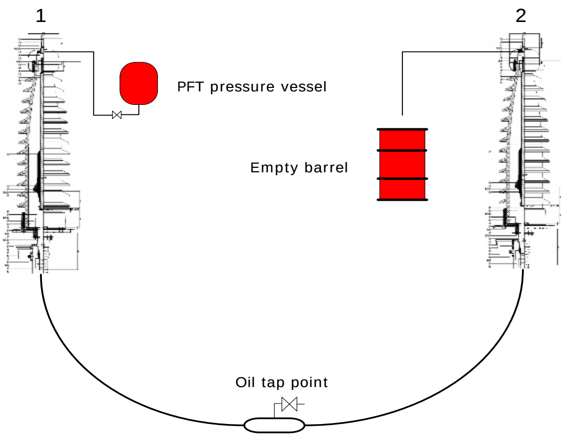

figure 2 'scheme for injecting PFT in the type test loop'

A pressure tank filled with PFT was connected to one of the terminations. After the pressure tank with PFT oil was opened, the oil channel of the cable was flushed with PFT (figure 2). Please note that the oil filled system was under atmospheric pressure during this procedure as the termination could not be closed due to oil injection modification (figure 1).

An oil extraction point was created for easy oil sampling in the middle of the test loop (figure 2). The tap point was opened, leaking about one drop of oil per minute resulting in ~ 1 liter per 24 hours. Oil samples were taken on a regular basis for PFT measurements. After one and a half day PFT was found in the oil from the tap point and after 4 days the value of the PFT concentration was stable, confirming the presence of PFT inside the cable insulation as this is the only path for PFT injected oil to reach the tap point. In conclusion:

- The test setup was under atmospheric pressure.
- PFT oil was injected only into the oil channel of the LPOF cable.
- After one and a half day, PFT penetrated through the paper layers of the LPOF cable.

After this experiment the test setup was restored for type test by closing the termination and increasing the oil pressure to normal values.

Type test

The Type Test program is based on IEC 60141-1 (1993) [4] and is summarized hereunder:

1. Dielectric loss angle/ temperature test, IEC 60141-1 § 4.3, U=87kV, tan δ measured at 20, 75, 60, 40 and 20 ^{o}C, requirement: tan $\delta \leq 33 \times 10^{-4}$.

2. Heating Cycle Voltage test, U=174kV, 10 heat cycles (8/16h), conductor temperature between 75 – 80 ^oC for at least 2 hours in hot condition,
3. Dielectric loss angle/ temperature test, IEC 60141-1 § 4.3, U=87kV, tan δ measured at 20, 75, 60, 40 and 20 ^oC, requirement: tan $\delta \leq 33x10^{-4}$.
4. Dielectric security test, IEC 60141-1 § 4.4, U = 220kV / 24hours, requirement: no breakdown.
5. Lightning Impulse voltage test, IEC 60141-1 § 4.5.2, Impulse voltage = 550kV 10+/10-, conductor temperature between 75 – 80 ^oC for at least 2 hours, requirement: no breakdown.
6. A.C. voltage test after the impulse test, IEC 60141-1 § 4.5.4, U = 184kV for 15min, requirement: no breakdown.

All tests were passed successfully without remarks.

4 – PILOT PROJECT

The PFT pilot project is implemented in the 50kV grid of Alliander (Dutch DSO): in their 50kV grid a total of 1000 km three core LPOF cable is still in active service installed from the 1950's until the late 70's. A picture of a typical three core LPOF cable is shown in photo 5.

Photo 5 'example 36/50kV 3core LPOF cable'

Name	Year	Section (km)	Type
DVD-WSP 1	1963	3,7	VGPLKod 3x120 36/50kV
DVD-WSP 2	1963	7	VGPLKod 3x120 36/50kV
HRNG-OTL	1964	5,1	VGPLKod 3x120 36/50kV
HRNG-PDRS	1957	5,5	VGPLKod 3x120 36/50kV

Table 1 '50kV LPOF cable systems data'

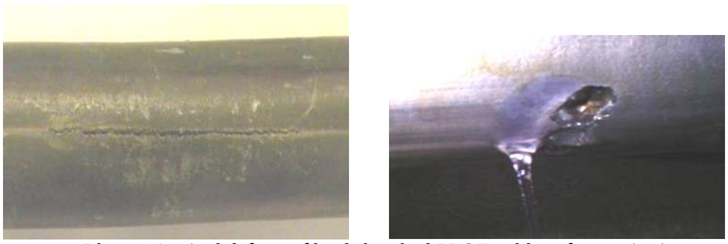

Photo 6 'typical defects of lead sheathed LPOF cables after ageing'

Small leakages (<5ltr/day) are non-detectable with traditional freezing methods, therefore a new strategy with the use of PFT technology was adapted by Alliander. After careful considerations the pilot project was initiated on four cable oil sections. Relevant data may be found in table 1. These four sections have leakage history over the last decade with non-detectable cause. See photo 6 for typical leaking defects that can occur in LPOF cable lead sheath due to fatigue.

Each selected section was surveyed and an appropriate PFT injection plan was created. A different PFT injection method was developed for each section; the plan depending on height profile, number of pressure tanks and number of joints in the oil section. Basically this PFT injection method consists of injecting and withdrawing oil for a minimum amount, but not according to the full flush method. It is anticipated with this method that due to the cyclic rating of the cable circuit, and hence cable temperature variations, the PFT enriched oil will be distributed along the cable circuit in time. This new injecting method saves PFT enriched oil, time and minimizes disturbances for the grid. The pilot test is still running.

One remarkable result was found on a pilot project on a 150kV LPOF cable system. This circuit was leaking oil at a slow leakage rate: 18 ltr per week. Detection was initiated, using Prysmian detection van, see photo 3, but no leakages were found along the cable route.

Photo 7 'hand held PFT sampler'

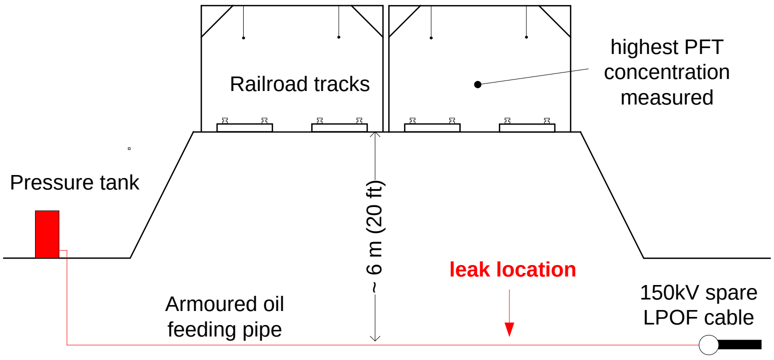

figure 3 'detected oil leakages in armoured oil feeding pipe under rail track'

Eventually, with the aid of the hand-held PFT sampler (see photo 7), the leakage was detected in an oil feeding pipe between a pressure tank and LPOF joint connected to a 150kV LPOF spare cable, despite the fact that:

- The leak was located underneath a railway crossing at ~ 6 m (20 feet) depth, thus the PFT had to diffuse through 6m of soil before it could be detected and
- the busy traffic on the railroad tracks disturbed the PFT detection, see figure 3.

It proves the effectivenes of PFT as a oil leakage detection system for small leakages.
Further application of PFT injection into LPOF cable systems will be roll-out in order to allocate small leakages, full-filling their obligation for environmental enterprising.

5 – UNITED KINGDOM PFT EXPERIENCE

The PFT technique was developed and fine-tuned in the UK a few years before it was introduced in the Netherlands. In the UK the regional electricity companies have been slow in taking on board the merits of topping up slow leaking circuits with "PFT injection during service" solution during routine cable system pumping. Generally the method employed so far has been to flush an equivalent oil volume to the loose cable circuit oil volume with new degasified cable oil mixed with a controlled dosage of PFT. To allow time for the PFT to permeate through to the ground level before the survey is carried out PFT detection is normally carried out after a period of about 14 days. To date Prysmian UK have successfully tagged 14 cable circuits and have located more than 25 leaks with a 100 % detection success rate. The "full flush" method with known final concentration of PFT allows very quick leak detection on circuits not previously tagged that suddenly increase in leakage.

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