

An innovative method for finding leaks in oil filled high voltage cables

by R H Goodwin, HV Test

Oil filled cables still form a major part of the high voltage (>33 kV) cable network in many countries. These cables are extremely reliable until they are damaged and start leaking. Pollution of ground water and environmental damage as a result can be a major problem.

Fluid filled (FF) cables form the backbone of transmission cable networks for a large number of major utilities. The voltages vary from 33 kV to 275 kV. In South Africa there are 200 circuits varying in length from 500 m to 10 km with an estimated total length of 600 km, and with voltages from 33 to 132 kV. The move away from FF cables is mainly due to cost and environmental issues.

These cables are extremely reliable and, provided the oil pressure is monitored and maintained, they give very little trouble. Oil filled cables are basically a pipe filled with oil with the paper insulated cores lying inside. The oil is free to migrate down the pipe and should there be any damage to the outer pipe, the oil will leak out causing a rapid drop in pressure.

FF cables are protected with pressure alarm contacts which, when operated, may result in the cable being disconnected. If pressure is maintained by header tanks the cable will be left in service while the leak is located. Up until 2008, there were very few methods for locating these leaks. The most commonly used method was the "Freezing method" using liquid nitrogen to isolate sections. A number of leak locating methods have been introduced over the years but the latest PFT tracer method is the most effective and can be done "live".

Oil filled cables

The cables are called oil filled cables or fluid filled cables and the conductors are insulated with paper tapes impregnated with and lying in insulating oil. Unlike lower voltage (MV) cables, these are held under pressure using header tanks. There are two types of FF cables.

- High pressure type (HP) – up to 9 bar and mainly used on EHV cables.
- Low pressure type (LP) – up to 4 bar.

In the H.P. cables oil is circulated continuously between two cables – e.g. two separate feeders, whereas LP FF cables have static header tanks. Typical L.P. cables are shown in Fig. 1. Monitoring of oil pressure is critical. These cables are protected using lead or aluminium sheaths which provide an excellent earth fault path. This sheath is covered by an outer insulation layer for protection against damage whilst in operation and during installation. These cables are very

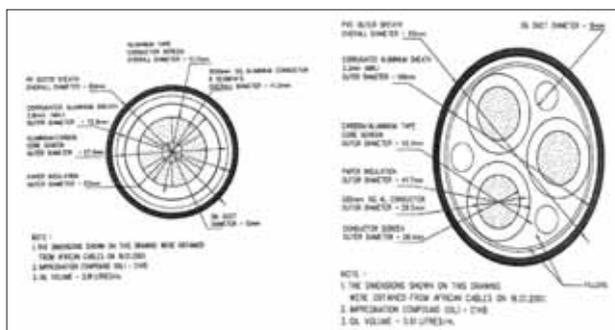


Fig. 1: Typical LP fluid filled cables.

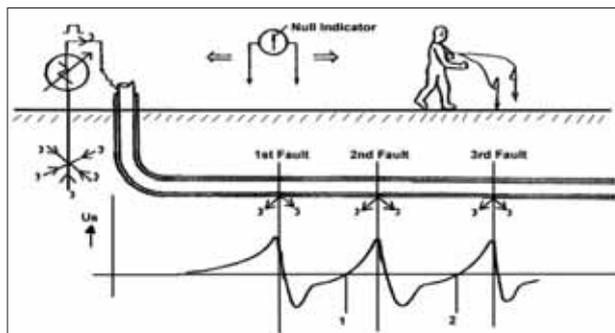


Fig. 2: DC voltage drop method.

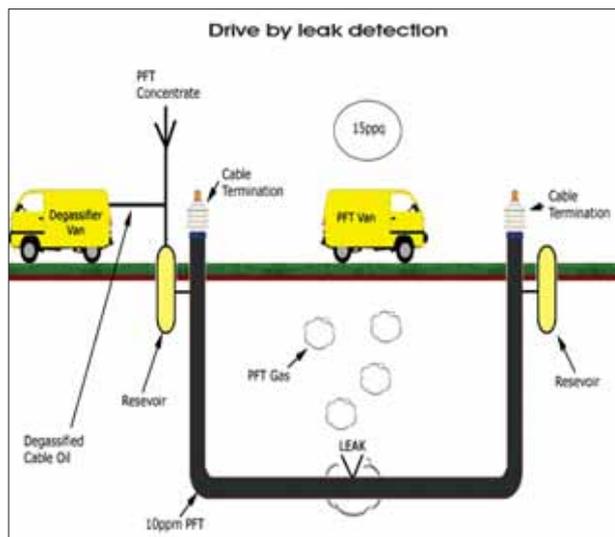


Fig. 3: PFT injection .

expensive to manufacture and there are very few suppliers left in the world. XLPE cables have superseded FF cables.

Cable oil leaks

FF cables are extremely reliable until they

start leaking. The location of these leaks has been a major problem because of:

- Environmental damage caused by leaking oil
- Difficulty in locating leaks.

Leaks usually start small and increase with time, and provided the pressure is maintained by the header tanks, and/or additional mobile backup tanks, the cable can continue operating. Location of these oil leaks has traditionally been done using the “freezing method” where liquid nitrogen is used to freeze the cable oil at different locations and then determining on which side the pressure continues to drop. This location method could take up to 10 freezes. During these freezes the cable is off-line and losing revenue. Each freeze could cost up to R150 000 taking all factors into account. Freezing also damages the outer insulating jacket which could result in water ingress and corrosion of the metal sheath, producing further leaks. Another disadvantage is damage that could be done to adjacent cables during excavation. Some leaks can take up to a year to locate with this method.

DC voltage drop method

This method is well known for locating outer jacket faults on cables. A D.C. Voltage is applied to the metallic sheath at one end whilst the other lead is connected to a reference earth spike. Current will flow down the metallic sheath to the point where the outer jacket is damaged and then flow back to the earth spike (Fig. 2). The test voltage can be up to 5 kV.

Pin pointing earth spikes are then used in conjunction with a galvanometer to locate the fault. The basic assumption is that the cable leak is where the damage to the outer jacket is. Leaking FF cables unfortunately insulate the soil in the vicinity of the leak. A further aggravating factor is that the higher the DC voltage is, the higher the “burning” current and the larger the leak becomes. As the area is saturated with oil, the DC leakage decreases making the method difficult.

The PFT tracing leak location

In 1988, ConEdison in New York approached EPRI and Brookhaven National Laboratories to develop a leak detector for their FF cables. ConEd have high pressure (20 bar) fluid filled cables (HPFF) and low pressure fluid filled cables (LPFF) (4 – 6 bar). They still form a major part of their transmission system [1]. The HPFF cables normally consist of two pipe circuits with oil continuously circulating between the two pipes. Oil pressure is continuously monitored by a PC. FF cables develop leaks due to:

- Contractor excavation damage.
- Corrosion.
- Outer jacket damage by freezing or third party.
- Stray currents due to DC traction.
- Mechanical damage from poor laying techniques.
- Road works – vibration and compression.

PFT's are perfluorocarbon tracers, which were developed by Brookhaven National Laboratories and which have unique properties of being liquid at room temperature, totally non-toxic and thermally inert. PFT is man made and does not exist as a natural gas in the atmosphere. It was estimated in 2009 that the concentration in the atmosphere was eight ppq, that is 8×10^{-15} [4]. Any detector must have the ability to detect this background concentration level. So the detection of small amounts of this gas in a specific area is absolute necessity.

PFT has the following advantages:

- In these very small quantities (10 – 100 ppm) that are introduced in the cable as a tracer, the insulation properties of the oil are not compromised.
- The gas is very stable and inert.

- Unlike SF6, PFT's do not deplete the ozone layer [4].
- PFT's do not oxidise in the atmosphere [4].
- PFT's have very low boiling points and are an ideal tracer for oil filled cables. (Whilst under pressure in the cable, the PFT remains in suspension – once it is released via the leak (atmospheric pressure) the PFT becomes a gas easily permeating the soil into the atmosphere).

Oil filled cable hydraulics

LPFF cables can withstand pressures up to 8 bar but generally operate at 4.5 bar. In order to keep these cables under pressure and to have reserve oil (in the event of a leak) a cable run will consist of a number of hydraulic sections with reservoirs on both ends. The geographical profile of



Fig. 4 a, b, c: Test van containing PFT detection equipment.

detection of the leaks more difficult but once the PFT gas is detected the final pin pointing is just a matter of time.

The detector is designed to read down to very low values of PFT, and may become "flooded" if there is high PFT concentration. The test van has to purge the detector of the excessive volumes of PFT gas. Bar holes are then used to pin the actual leak. Here a portable sampling bag is used to collect samples.

Tagging difficulties

To introduce the tracer, a degassifier oil van is required in order to have purified oil with less than 20 ppm moisture and no free gas. The tracer is introduced into the purified oil just before it is introduced into the cable system. LPFF cables normally have spiral ducts, conductor tubes or even space between the conductor where free oil can move through the cable. (Fig.1). The oil (and PFT) travels relatively quickly down the cable. In some single core cables it is difficult to circulate the oil because of the configuration, and oil is trapped in the insulating conductor papers.

Mobile leak detection unit

In South Africa, mobile leak detection consists of a test van containing the PFT detection equipment. Inside the van the following equipment is required:

- Super silent portable generator to power the equipment and to provide lighting.
- Alternatively a battery pack and inverter.
- Vacuum sampling device.
- Gas concentrator.
- Gas chromatograph and detector. (GC)
- Carrier gases.
- Control desk and lap top.
- GPS Satellite Receiver.

Figs. 4, 5 and 6 illustrate typical configurations.

The latest units have GPS satellite location which allows the leaks to be automatically tagged while driving along the cable route. See the map in Fig. 7. with waypoints. The red waypoints indicate where PFT was detected.

Final pinpointing is done by using bar holes and taking sample bags. The sample bag with the highest concentration will indicate the exact location of the leak. The degassifier truck and the point of connection to the cable system, should be free of leaks and spillage to avoid affecting the PFT detector.

A very useful sampling device is the CATS (Capillary absorption tube sampler) which can be used to measure the PFT concentration. This is a small glass tube filled with a material which absorbs the PFT. These CATS can be placed on fence



Fig. 9: Typical sheath leak.



Fig. 10: Typical sheath leak.

poles, pylons, poles etc. along the route of the cable. These are then analysed by the concentrator and GC.

Mobile detector

The mobile detector samples the ambient air as the vehicle navigates the route. The batched sampled air is then concentrated in special traps, designed to trap the PFT and other gases. The gas is then passed on to a gas chromatograph and finally to an ECD (electron capture detector) using a radioactive source. The GC software is designed to "look" for a particular trace which is an indication of the magnitude of that particular PFT gas. The software that is used for the analysis is very simple and a sample of the output is shown in Fig. 8.

Experiences in South Africa using the PFT leak detection

In South Africa, H.V. Test has been using the PFT method of leak location for the past two years. To date 39 leaks have been located. An analysis of the type of leaks is as follows:

- Band wipes- 5
- Repairs sleeves-3
- Cable wipes-10
- Pumping lines- 6
- Barrier- 2
- Pumping nipple-1
- Cable sheath- 12

Most of these cables were installed 40 years ago. It is interesting to note that cable sheath leaks are 30% of the total leaks. It is very important to record exactly the amount of cable oil that is pumped

in order to determine if the entire cable length is tagged.

Some typical sheath leaks are shown in Figs. 9 and 10.

Conclusion

The PFT tracer leak location is technically and economically a viable method of leak location in fluid filled cables. Other methods are unreliable, time consuming and damaging to the leaking cable and adjacent cables. Recycling of the cable oil should be carefully considered because of the financial benefits. The PFT tracer technology for leak location will reduce the leak location time to hours instead of months and years. With this latest technology, fluid filled cable users will be able to account for every litre of cable oil that is lost due to cable leaks.

References

- [1] Leak location in fluid filled cables using the PFT method. R Ghafurian, R N Dietz, T Rodenburg, J Dominguez, N Tai. IEEE Vol. 14 No. 1 Jan. 1999.
- [2] Balfour Beatty paper.
- [3] Experimental design data of the April 1997 multitracer atmospheric experiment at Idaho Memorial Engineering Laboratory* L.A. 7795-M5 Los Alamos Scientific Laboratory 1979. Various Authors.
- [4] Environmental research technology Brookhaven National Laboratories. New York.
- [5] Vapour detection of trafficking of contraband money. Brookhaven National Laboratories. New York.
- [6] Wasson-ECE tracer analyser.

Acknowledgment

EDF – Allan Croucher, Paul Williams for the valuable advice.

Contact Ron Goodwin, HV Test, Tel 011 782-1010, ron@hvtest.co.za ❖