Methods of Maintenance on High Voltage Fluid Filled Cables Including an Innovative Technology Associated with Dielectric Fluid Leak Location

by Mike Engelbrecht – CBi electric: african cables

Abstract

During April 2007 Bedfordview experienced a 67 hour blackout caused primarily by leaks on two 132kV fluid filled cables which subsequently led to breakdown of the cable insulation. This paper serves to address the issues surrounding maintenance of fluid filled cables including cable circuit assessments, breakdown maintenance, refurbishment maintenance and planned preventative maintenance, all of which could be used to pre-empt a Bedfordview scenario.

Also introduced is an effective means of oil leak location, as adopted by CBi electric: african cables, and planned for roll out in the latter half of 2008. This method of leak detection locates Per Fluorocarbon Trace (PFT) that has been previously injected into the cable system. The PFT is detected by means of a mobile detection unit and is currently in operation in both American and British electrical utilities having successfully located in excess of 80 leaks on both high pressure and low pressure fluid filled cable circuits to date.

Background

Fluid filled cables have been installed in South Africa since the late 1960’s, early 1970’s with a wide variety of types (BICC, Pirelli, Sumitomo, Dainichi-Nippon). Oval conductors, round conductors, hollow core, copper and aluminium and various sizes in both three and single core options currently convey power country wide with voltages ranging from 33kV up to and including 132kV [1,2].

The cable construction constitutes paper insulation augmented by cable oil, under pressure, in order to improve electrical properties and avoid partial discharge activity. Oil pressure is maintained by either a corrugated aluminium or lead sheath/metallic tape combination. All local major utilities have these cables in their system and they are all of the low pressure oil filled type, typically designed to operate at 3-4 bar pressure.

Over time these cables are beginning to leak cable fluid and subsequently the cable pressure drops. Without maintaining cable pressure the cable insulation eventually fails. Causes of leaks can be categorized as follows:

- Degradation of lead wipes on accessories. This is especially valid if these wipes have not been re-inforced during assembly (a typical practice).
- Lead fatigue if the system is over pressurized.
- Third party damage leading to rupture of the metallic sheath (the most common cause).

In addition to the leaking circuits, further reduced reliability has been associated with fluid filled cables, within South Africa, due to the following aspects:

- Normal design life being of the order of 30 years with many of the fluid filled cable circuits in operation in excess of this duration.
- A significant reduction in the skills associated with repair, with many personnel skilled in such tasks having either left South Africa, to return to their homelands, or even retired.
- An absence of training with OEM jointing schools having closed down.
- A significant decrease in maintenance on fluid filled systems due to pressure on operating budgets.
- A decreasing pool from which to source spares.

The above aspects have resulted in a dismal outlook for the future of fluid filled cables locally. However, as shown in Table 1 [2], there are still many of these circuits in operation. Local utilities cannot merely replace all these circuits, due to cost and time constraints and the challenge therefore remains to improve the working condition and reliability of the existing fluid filled circuits, thereby averting further outages. Systematic replacement, as budget spend becomes available, can then be adopted.

How then to address the various problems associated with ailing fluid filled cable circuits within local utility networks?

The answer is three fold:

- First, it is necessary to assess what the relative condition of the fluid filled circuit currently.
Second, a decision needs to be taken as to the future of the cable circuit i.e. is it beyond repair or can it be re-instated to original design parameters?

Thirdly, leaks on fluid filled cables remain the single biggest clue to indicate an impending electrical fault in the not too distant future. Repair these and the reliability of the circuit immediately increases.

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Circuit length (km)</th>
<th>Cable length (km)</th>
<th>Quantity of accessories</th>
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<tbody>
<tr>
<td>1</td>
<td>132kV fluid-filled cable</td>
<td>222</td>
<td>355</td>
<td>710</td>
</tr>
<tr>
<td>2</td>
<td>88kV fluid-filled cable</td>
<td>85</td>
<td>130</td>
<td>260</td>
</tr>
<tr>
<td>3</td>
<td>66kV fluid-filled cable</td>
<td>269</td>
<td>341</td>
<td>682</td>
</tr>
<tr>
<td>4</td>
<td>44kV fluid-filled cable</td>
<td>48</td>
<td>48</td>
<td>96</td>
</tr>
<tr>
<td>5</td>
<td>33kV fluid-filled cable</td>
<td>373</td>
<td>373</td>
<td>748</td>
</tr>
<tr>
<td></td>
<td>TOTAL FLUID-FILLED CABLE</td>
<td>997</td>
<td>1 247</td>
<td>2 496</td>
</tr>
</tbody>
</table>

Table 1: Fluid filled cable in operation in South African Utilities

Cable assessments

Information from condition based monitoring is rarely, if ever, available on fluid filled type cable systems due to inadequate maintenance. The first step therefore, towards returning the fluid filled cable asset back to full design capability is to obtain a snapshot of how the cable system currently operates. To this end, it is necessary to assess the cable circuit’s current working status.

Any historical operational information is helpful in this regard including facets such as number of failures, number of fluid leaks, number of fault current exposures etc. Invariably the most basic elements such as design profiles and operating manuals are however enough to get started.

Measurements including oil analysis, pressure checks, serving tests, earthing checks and general operating conditions are all determined during the cable assessment. Also of interest is the inspection and stock take of the types of accessories available in order to effect a repair on the cable should a breakdown occur. Upon completion of the circuit assessment a report is produced detailing the findings and necessary recommendations can be made as to the maintenance path ahead as illustrated in Figure 1.

Category One would be interpreted as the cable circuit being:

- In good working order:
  - No immediate work is required other than routine annual maintenance.

- In fair working order:
  - Refurbishment of the joints / ancillary work and routine annual maintenance will ensure that the cable returns to designed working order.

Category Two is interpreted as the cable circuit being in an unacceptably poor working condition, i.e. breakdown maintenance could be utilised to patch but the circuit would, ultimately, need to be replaced.

Refurbishment maintenance

One local utility has already instituted a refurbishment programme on its aging gas and fluid-filled cables. This type of maintenance involves exposing, inspecting and servicing cable joints. Work is done in off peak periods with no power outages to customers, the down side being that it is extremely time consuming with typically one accessory completed over a week end.

This type of maintenance also only concentrates on potential leak areas and is therefore limited, it does however prevent leaks from occurring at one of the most common leak areas on the cable circuit.
**Planned Preventative Maintenance**

The planned preventative maintenance scheme encompasses a similar scope to that of the cable assessment as detailed above. The planned preventative maintenance is effectively a condition monitoring programme and is conducted on an annual basis with any defects, highlighted by the various tests, repaired immediately.

The single biggest advantage associated with a planned preventative maintenance scheme is that it ensures that the utility keeps its fluid filled cable circuits in good working order. Furthermore, test results over time begin to give an excellent indication as the natural ageing of the various cable components. Planned replacement forecasting becomes easier and technical motivation based on reliable long term tests is a reality.

**Break Down Maintenance**

This is the catastrophic scenario. The lights are out and immediate repair of the circuit needs to be effected. The most important aspect relating to breakdown maintenance is having the necessary spare parts in order to perform the repair.

Lead times on fluid filled accessories are typically in excess of 16 weeks, are exclusively imported and are extremely costly. In addition to these constraints, due to the wide variety of cables and manufacturers that developed these systems (many of whom do not exist any more) the supplier needs to be furnished with exact cable details at time of order placement and the accessory is then custom made, from scratch, to fit that specific cable. The consequence here is that spares are not easily interchangeable and many different spares need to be catered for due to the variety of cable constructions and types that exist in the South African electrical network.

Once the point of breakdown has been located and exposed, and the necessary accessories and/or cables are available for repair, it is still time consuming to repair the cable due to the complexity associated with a fluid filled, pressurised system. Also, once the cable is repaired, the cable fluid required to replenish that which was lost or removed during the fault must be de-gassed and circulated. Only once the necessary dielectric strength has been obtained may the circuit be returned to operation.

**Utility Responsibility**

Specialised equipment and highly skilled and qualified personnel are required to conduct all types of maintenance on fluid filled cable circuits, these expertise are locally available from CBi Electric: African Cables and there is therefore no reason that utilities should not be utilising these resources in order to maintain their fluid filled cable circuits. The Bedfordview disaster has also set a strong precedent for local electrical utilities, sending a clear warning sign of what happens when it goes wrong on a major fluid filled cable circuit. Furthermore, in these times of load shedding, utilities can ill afford to have additional outages due to a poorly maintained fluid filled cable network.
Innovative leak location on fluid filled cable systems

Background

As mentioned above, one of the most common problems associated with fluid filled cable circuits is the leaking of cable dielectric fluid into the surrounding environment. Many of these cable circuits cannot be taken out of service due to their strategic nature and cable pressure is therefore maintained by regularly pumping up the cable system. This invariably results in over pressurising of the cable and could exacerbate existing leak sites leading to further leaks.

Traditionally, fluid leak location has been conducted via cryogenically freezing the cable fluid and then monitoring the cable pressure either side of the freeze. The leaking section is progressively halved until the leak is located approximately within 10m-20m. The effected length of the cable is then exposed and the leak visually located.

Limitations with this method include the following:

- The cable circuit needs to be out of service in order to perform the freeze.
- Freezing pits need to be excavated along the route in order to access the cable.
- It is difficult to locate more than a single leak on the same cable section.

Per Fluorocarbon Trace (PFT)

During 1998 Brookhaven Laboratories (USA based research laboratory), Con Edison (New York based utility) and EPRI (USA based research organisation) reported on leak location in fluid filled cable circuits utilising the Per Fluorocarbon Trace (PFT) method [3]. This method of leak detection uses small traces of PFT liquid, dissolved into cable dielectric fluid and injected into the cable system. At a leak location, the PFT leaks into the soil and vapourises (See Figure 2). The vapour is then detected by means of a mobile detection unit, housed in a test vehicle.

![Fig. 2: Schematic of principle of PFT operation.](image)

Atmospheric concentrations of PFT are extremely low and any measurement of concentrations of PFT in the atmosphere at concentrations higher than atmospheric volumes then points to a leak from a cable circuit, previously tagged with PFT. Leak rates of 100 litres/week have been shown to be detectable and sensitivities in the 200ppq range are reliably measurable with the detection unit.

Advantages with the technology include the following:

- The cable need not be removed from service during tagging or leak location.
- The measurement is extremely sensitive and an accuracy of 2m or better is feasible, thereby minimising the amount of excavation.
- Many simultaneous leaks can be detected on a cable section.
The technology is relatively inexpensive in that it costs roughly 138% of the cost associated with locating a leak via cryogenic freezing.

South Africa and PFT

The biggest South African utility is currently in the process of adjudicating tenders associated with PFT. The technology has been proven in both American and British electrical utilities and has been shown to be most effective, having located over 30 leaks alone, in the past year, on a prominent London based utility’s low pressure oil filled cable network. Work is planned to commence in the latter half of 2008 on South African cables and once it is shown to be successful locally it is envisaged that other South African utilities will follow suit in order to procure the technology.

Conclusion

The paper has served to highlight the risks associated with ageing fluid filled cable circuits within the South African electrical supply industry. Solutions regarding maintenance of these systems have been highlighted and it is proposed that these methods, correctly implemented, can return the cable circuits to operational design parameters and extend the longevity of the asset, thereby enabling sound network planning moving forward. Adequate spares requirements are imperative in order to deal with breakdowns of the cable networks in operation.

Also introduced is an innovative method, utilising PFT to locate leaks on fluid filled cables. The method is due for implementation in South Africa in the latter part of 2008.

Acknowledgement

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References