SELF-HEALING DIELECTRIC FLUIDS FOR FLUID FILLED CABLES: FROM LAB TO CIRCUITS

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ABSTRACT

We present here recent findings regarding the further development of self-healing dielectric fluids (SHFs) for autonomous leak sealing in fluid filled cables (FFCs). Having previously demonstrated the efficacy of the concept (both in open air and backfill conditions) we have continued to develop the formulation and testing equipment including the construction of bespoke, fully instrumented cable testing rigs for performance evaluation under operational conditions. We also present further advances in the purification of the SHF for electrical applications as well as scaling production to volumes required to carry out circuit trialling in collaboration with supporting UK network operators.

KEYWORDS

Dielectric fluids, self-healing fluids, power cables, fluid filled cables.

INTRODUCTION

Fluid filled cables (FFCs) are present throughout European electricity networks as legacy systems, dating from before the development of polymer dielectrics for MV and HV systems. Although most have been subsequently replaced, a substantial network still exists (with 7,860km in the UK alone) often located in areas where replacement is either impossible or prohibitively expensive.

An example design of a fluid filled cable is shown in Figure 1. Compared to a polymer-insulated cable, the insulation layer of a FFC consists of tightly lapped cellulosic (or polypropylene-paper laminate paper - PPLP) paper impregnated with a low-viscosity dielectric fluid. As well as providing electrical insulation, the fluid fills voids within the paper (thereby preventing partial discharge) and enhances thermal transport away from the conductor. To ensure the system is fully impregnated, the cables are held under a positive pressure (between 3-5 bar with potential transient pressures of up to 8 bar) and are contained within a lead or aluminium sheath. Although this is effective at preventing void formation, it also means that oil will leak rapidly through any holes in the outer sheath or at joints. This problem is exacerbated by the very low surface energies of commonly used dielectric fluids, which means that leaks can occur through defects that are only microns across.

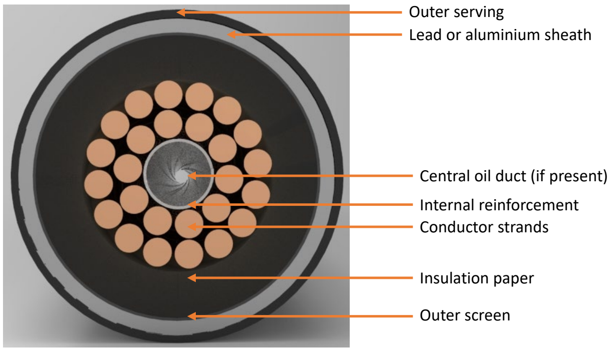

Figure 1. Schematic of a hollow core self-contained fluid filled cable

In the event that the sheath is breached, fluid will leak from the insulation layer into the surrounding environment. This presents two problems; for the cable, a significant loss of fluid will lead to the accelerated aging (and eventual failure) of the insulation paper. While this can be averted through replenishment, the fluid already lost presents an environmental hazard and operators can face fines and high costs for unplanned emergency maintenance, particularly if the leak occurs in an environmentally sensitive region. In the UK, operators are required to report leaks if they breach particular thresholds (typically 40L a month) and take immediate action to prevent further loss of oil. As with other underground cables, this necessitates locating, diagnosing, and excavating the leak so that a repair can take place [1], which is expensive and time consuming. Although techniques have been developed to locate leaks (including tagging circuits with perfluorocarbon tracers) these can be misleading, resulting in false negatives or the detection of cable fluid some distance from the actual site.

The extent of this problem is significant and serious. As seen in Figure 2, annual fluid losses between 2014 and 2017 ranged from 330,000 to 411,000L [2], representing 2.9% of the total oil capacity. Although the general trend has been towards leak reduction, it can be seen that there is a significant increase in the 2017-2018 period, meaning that the overall reduction in fluid loss from 2015-2018 is just 1.8%. As many fluid filled circuits are now operating substantially beyond their operational service lifetime, there is an increasing risk of sheath failure through galvanic corrosion or (in the case of lead sheathed cables) sheath crystallisation and embrittlement. Of these, crystallisation is of particular concern, as crystallised lead is prone to catastrophic, brittle fracture, and is sufficiently fragile that attempts to joint or repair the circuit often results in further damage.