Degradation of silicone insulating fluids in cable sealing ends

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ABSTRACT

Polymeric cable sealing ends (CSE) typically contain silicone oil as an insulating fluid. In recent years a number of performance issues have been identified with silicone filled CSE on the UK network. In order to manage these assets effectively, it is important to investigate possible reasons for the unexpected service experience. This paper presents a review of the properties of the silicone fluid, the outcomes of measurements and chemical analysis on a range of samples of new and used silicone fluids. We also present the results of a fully three dimensional thermal and electrical finite element model of the CSE, which helps to demonstrate the conditions experienced by the silicone fluid when in service in a CSE.

KEYWORDS

Silicone fluid; cable terminations; cable sealing ends; finite element analysis; service experience.

INTRODUCTION

Understanding cable systems performance in more detail, can allow asset owners to unlock more value from their existing asset base, reduce the amount of precautionary work undertaken, and allow more targeted interventions to reduce risk.

While cross linked polyethylene (XLPE) cable systems have been available since the mid-1970s, their use in the UK has only become prevalent since the early 1990s; making the oldest XLPE cable systems in the UK around 30 years old.

XLPE cable systems where introduced into the UK with an expected lifetime of around 40 years. Past and recent experience has shown that XLPE Cable Sealing Ends (CSEs) are subjected to accelerated ageing in specific instances. Accelerated ageing is often identified through several markers within the CSE's oil; such as dissolved gasses, moisture levels, and reduced breakdown strength.

Early life degradation is generally due problems during installation or manufacture. This type of degradation is often identifiable from the post mortem inspections; where enough of the asset remains intact for an inspection.

Mid-life accelerated ageing, is harder to identify as the driving forces behind the ageing are thought to be slower acting. Based on what is known today, this type of accelerated ageing can come from several sources; chemical contamination, chemical incompatibility, and an increase in moisture within the CSE.

The latter is often the most frequently cited. In these instances, it is critical to remember that the moisture seen in CSEs can come from three sources:

1. Ingress through environmental seals
2. Installation
3. The materials within the cable system.

Determining the exact reason behind accelerated ageing markers is particularly challenging for CSEs as they tend to be seal for life units. This means that internal inspections are only undertaken when external observations have identified an issue with the asset. This makes benchmarking any post mortem results difficult; as an asset owner may have no basis for comparison.

Further complicating the interpretation of accelerated ageing markers, is the lack of information around the possible chemical interactions between the materials within a CSE, which direction moisture is likely to migrate during heating and cooling, and the expected thermal and electrical stresses on the materials under normal and abnormal conditions.

This paper presents thermal and electrical models of a generic 132 kV CSE. These models can be used to inform asset owners on the conditions that a CSE is exposed to during operation; and hence inform some of the critical questions relating to the interpretation accelerated ageing markers.

This information can then be used to inform tests to explore the chemical changes which the silicone oil might witness under these conditions. The results are used to identify possible degradation pathways, which might be responsible for the degradation seen in CSEs installed on the UK transmission network.

CABLE SEALING END DESIGN

CSEs form the transition between a cable and another insulation system. We focus here on outdoor CSEs which interface a cable system with and an Air Insulated System (AIS). This paper will also be focusing on silicone oil filled 'wet' type CSEs, and largely excludes dry type CSEs from discussions. A simplified view of a CSE is shown in Figure 1, which shows the basic components that are contained within a CSE.

SILICONE OIL PROPERTIES

Silicone oil, also known as polydimethylsiloxane, is used as an insulator in cable sealing ends (CSE) of cross-linked polyethylene (XLPE) cables. It is widely considered compatible with structural elements used in current CSE. The term "silicone" refers to the analogy between silicon compounds and the equivalent oxygen compounds of carbon (polysilicoketones). However, the Si-O-Si group is better described by the term "siloxane". Silicone oil should correctly be termed "polysiloxane liquid". Silicones are synthetic substances, and the organosilicon linkage is not found in nature.