IMPACT OF MOISTURE MIGRATION ON THE CURRENT RATING OF HIGH OPERATING TEMPERATURE CABLES

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ABSTRACT

Operating temperatures of conventional high voltage transmission cables are generally restricted to 90°C in order to prevent thermal damage occurring to the XLPE dielectric. However new polymeric dielectrics may allow higher conductor temperatures, potentially increasing the current rating of the cable circuit. For buried cables this increases the rate of moisture migration away from the cable circuit, thus increasing the ground thermal resistivity. This paper outlines the development of a dynamic backfill model which permits moisture migration to be modelled explicitly. The model is then used to determine the likely magnitude of rating increase available from the deployment of high temperature cables on the transmission network.

KEYWORDS

Current ratings; moisture migration; finite element analysis

INTRODUCTION

The current rating of a high voltage cable circuit is limited by the maximum operating temperature of the dielectric material used within the cable. In the UK transmission network, 400kV cross-linked polyethylene (XLPE) insulated cables are typically rated for a maximum conductor temperature of 90℃. This is considered to minimize the risk of premature ageing of the dielectric material. Recent research into polypropylene based cable dielectrics has suggested that their improved thermal properties may allow this limit to be raised to 120℃ [1]. Although much work remains to be done on the underlying dielectric materials, it is worth considering what benefits the new cable capability would bring at transmission level.

The calculation of current ratings for cables operating at higher conductor temperatures (hereafter denoted “HT” cables) presents a number of challenges. Raising the maximum conductor temperature will also raise the cable surface temperature, which will increase the rate of drying of the backfill local to the cable. This will lead to an increase in the overall ground thermal resistance and hence must be accounted for in the rating calculation. A further challenge is that the ground surface temperature may be elevated significantly above ambient and hence it is no longer appropriate to consider it isothermal.

This paper takes on these challenges by using a finite element technique to directly model the moisture migration around an example HT cable system. The model development process is outlined in brief, with the bulk of the paper dedicated to presenting the rating results obtained. This allows an appraisal of the potential operational benefits of the new cable technology for both steady state and emergency loading conditions.

EXISTING RATING TECHNIQUES

Traditionally buried cables are rated using the methodology outlined in IEC 60287 [2], which provides analytical equations for most common cable configurations. Section 1-1 of IEC 60287 presents a method by which the ground thermal resistance T4 can be modeled as comprising two distinct zones, one dry and one wet. The boundary of the two zones occurs at a specified isotherm. While this approach offers a key benefit in allowing the calculation to be done by hand, it does force a number of assumptions. Firstly the IEC 60287 method relies upon assuming an isothermal ground surface boundary. Previous research has shown that this can lead to optimistic ratings where cables are shallow buried [3], as in reality the heat transfer from the ground surface into the air occurs at a limited rate, governed by natural convection. This would cause the ground surface temperature directly above HT cables to rise significantly above ambient. The second key consideration is that the change in soil moisture content is unlikely to fit the step change suggested by the IEC 60287 method, meaning that selecting the correct location for the wet/dry isotherm is of critical importance.

Finite Element Rating Methods

Over the past decade, improvements in computing hardware have made Finite Element Analysis (FEA) a viable technique for calculating ratings. A significant number of studies have compared the performance of IEC 60287 with FEA methods, for instance [3]-[5]. Typically the agreement with IEC 60287 was good for more deeply buried cables, however [3] demonstrated that IEC 60287 can give optimistic values at shallow burial depths. However the true benefits of FEA are realized when calculations must be undertaken in non-uniform thermal environments. Several researchers have examined moisture migration using this method [6]-[7]. Given its proven potential in modeling moisture migration, FEA is adopted within this study to analyse the possible ratings of HT cables.

MODELLING MOISTURE MIGRATION

Moisture migration occurs around a cable circuit when the heat generated by the electrical losses in the cable begins to alter the physical properties of the water in the backfill local to the cable. As the water temperature increases, its surface tension will decrease, thus reducing the energy required to overcome the forces holding the water in the soil pore [8]. When the water content of a soil decreases, its thermal resistivity increases, with the result being a higher cable temperature for any given load. A number of models exist for the moisture migration process, however perhaps the most widely used is that of Philip and De Vries [9].