How can life assessment and diagnostic monitoring influence the choice of MV to EHVDC cables for interconnected grids

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ABSTRACT

This paper considers some of the challenges related to the design and long-term reliability of HVDC cables. To address this, a twofold approach is taken, (i) cable design and testing should be based on a proper understanding of ageing and failure mechanisms under operating conditions and (ii) model informed monitoring systems should be put in place to safeguard long term reliability. A methodology is proposed that allows well-defined choices for the cable design to be made and a monitoring and modelling strategy is described that enables proper asset management, leading to a level of reliability that is expected by network owners, operators and insurers.

KEYWORDS

HVDC cables; reliability; design; monitoring; modelling.

INTRODUCTION

Global developments in HVDC and EHVDC transmission present a number of challenges, perhaps the most eye-catching being the trend towards underground cable connections. The operating voltage for overhead lines has increased to 1100 kV in China. Different manufacturers have claimed cable operating voltages up to 640 kV but installed cables have so far been limited to 525 kV. Different approaches are being taken to move towards extra-high dc voltage (800 kV and above), but it is unclear at this moment if existing technologies can be successfully upscaled to higher voltages.

This paper will elaborate on the issues and ways in which they can be tackled to enable sound DC cable development to take place and to ensure that long term performance can be achieved through appropriate assessment and testing related to the operating stresses that will be experienced in practice. Not only is this paramount at a materials selection and design level, it is imperative to develop diagnostic and condition monitoring tools for insulating materials and cable systems working under DC conditions of high field and large currents in the field.

A poor understanding of ageing and failure mechanisms for DC cable systems operating in integrated networks and subject to non-sinusoidal voltage waveforms adds great uncertainty to the design, selection, assessment and testing of HV and EHVDC as well as MVDC cable systems. There is a need to select a design electric field at a given failure probability, which must be based on a secure knowledge of life models, thermal performance, long term insulation performance and modes of failure, which will be affected by waveform and time dependent electrical and thermal stresses.

With networks being increasingly subject to renewables generation, the whole life performance of cable systems has to be taken into account. For network investors, operators and insurers, the effect of these complex factors on residual life arising from the presence of partial discharges (PD) and space charge is not understood. Indeed, even the potential accelerated ageing due to harmonics and voltage spikes superimposed on the DC voltage is not known, even at medium voltage.

While the effect on lifetime of the prevailing ageing mechanism in polymeric materials under AC (i.e. PD) is known, the effect on long term performance of DC cables of PD is not, and also the way to measure PD under DC is not widely available.

Perhaps even more importantly, ageing processes can in the long term lower the threshold for space charge accumulation. The result can be a significant change of the internal field in the insulation and, when coupled with the thermal stress and voltage transients, there is an increased probability of short term failure, likely due to thermal instability, as well as cumulative whole life ageing arising from discharge and electro-thermal driven ageing.

We will show that this provides an imperative for measuring and monitoring space charge, as well as internal and external cable temperature. It also stresses the necessity of having appropriate ageing and life models to ensure that the cable system life will match the design life and, thereby, achieve the reliability expected by network owners, operators and insurers for both on-shore and off-shore networks and links. Such thinking must also extend to the optimum choice of cable system in terms of cost and reliability and the need to adopt condition-based maintenance and life extension planning with improved accuracy and reliability.

DESIGN AND LONG TERM RELIABILITY

While the majority of HVDC cable systems in service are based on mass impregnated and paper-oil insulation systems, current trends are towards the use of extruded polymeric insulation for their ease of manufacturing, higher operating temperature and lower weight. Since 1999, when the first XLPE HVDC cable was employed, the operating voltage and the current rating of XLPE based cables have incrementally increased. Only in the last five years has a remarkable acceleration in the "upgrading" of XLPE systems been seen, through taking great care of the cleanliness of the insulation and by improving semicon-insulation compatibility. The latter is receiving more attention since it has been shown that low-molar mass species may diffuse from a polar semicon into the insulation [1]. For the long term reliability, the chemical