Investigation and Qualification of ±320 kV HVDC cable systems for VSC and LCC applications

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ABSTRACT

Extruded HVAC cable systems up to 500 kV have been developed successfully in the past decades and several years of operating experience are available. Because of an increasing demand in power and the ability to transmit electrical energy over long distances, HVDC cable systems become more important. However, due to DC specific influences on the insulating systems of the cable and accessories, a detailed consideration and evaluation of these effects must be taken into account during the development process of extruded HVDC cables and their accessories.

This paper addresses the main influences of DC stress on the components of HVDC cable systems. Fundamental aspects regarding the interface between cable and accessory will be discussed. The paper describes the systematic investigation, development, and qualification of a U_0= ±320kV extruded XLPE HVDC cable system for VSC (voltage source converter) and LCC (line commutated converter) applications.

KEYWORDS

HVDC, cable system, XLPE, silicone rubber, joint, testing

INTRODUCTION

The increasing amount of regenerative energy sources and the large distance between energy generation and consumption requires the development of high and extra high voltage transmission systems. Especially, HVDC systems play a significant role for grid stabilization and the transmission of energy over very long distances. Due to their reliability and political framework conditions, high and extra high voltage cable systems are seen as the backbone of future energy grids. Polymer cable systems for HVAC applications up to voltage levels of U_m = 550 kV have been developed and are successfully in operation for several decades [1]. For HVDC systems self contained oil filled (SCOF) and mass impregnated paper (MIND) cables and their accessories are available for voltage levels up to U_0 = ±600 kV [2]. The development of VSC systems enable the application of polymer insulation systems, such as crosslinked polyethylene (XLPE). HVDC cable systems with polymer insulation offer essential benefits e.g. regarding economic and logistic aspects, cable accessory installation techniques, and transmission capacity due to higher maximum conductor temperatures. With the commissioning of the gotland project in 1999, HVDC cable systems with XLPE insulation have been commercially introduced for the first time [3].

The demand of increasing HVDC power ratings lead to the continuous development of higher system voltage levels. However, the impact of DC specific influences on the cable and cable accessories insulation system require a detailed understanding of the electrical system behaviour. Especially, the conductivity under field strength and temperature, space charge characteristics, material compatibilities, installation techniques, operation conditions, or manufacturing processes take an important role for a reliable design of HVDC cable system components. The complexity of a general understanding of the insulation system behaviour requires an advanced and systematic evaluation approach. The following paper addresses an overview of the main challenges of extruded cables and their accessories for HVDC applications. A systematic research and development approach will be described. A method for electrical material characterizations focusing on cross-linked polyethylene (XLPE) and various advanced silicone rubber compounds are discussed. The obtained material data are adopted to numeric field simulations. Extensive HVDC full-size cable testing is conducted and main results are presented.

CHALLENGES OF EXTRUDED HVDC CABLE SYSTEMS

Insulation systems for HVDC applications undergo a complex combination and coupling of material characteristics and system boundary conditions. Particularly, the resistive field distribution and the accumulation of charge carriers address an essential challenge within the design of HVDC system components. The following section will provide a brief overview of those aspects and their impact on HVDC cable systems.

Resistive field distribution

The electric field distribution in a conventional AC insulation system is controlled by the permitivity ε of the insulation material. This behaviour leads to a simplified time constant electric field distribution. In contrast to AC fields, the stationary electric field E under DC application is determined by flux field with conduction density J with:

$$J = \sigma \cdot E \tag{1}$$

The conductivity σ of a solid insulation material can be approximately expressed according to [4] by equation 2:

$$\sigma(E,T) = Ae^{\left[\frac{-\varphi \cdot q}{k_B \cdot T}\right]} \cdot \frac{\sinh(B \cdot |E|)}{|E|} \tag{2}$$

Here, φ is the thermal activation energy, k_B the Boltzmann constant, T is the temperature and q is the elementary charge. A and B are constants relating to the temperature and electric field dependency.

HVDC cable systems undergo various thermal and electrical operation stages. The coupling of electric field distribution with the material conductivity leads to complex electric field conditions in the cable system components as amongst others addressed in [4] and [7]. Resulting