Experimental Approach to Test the Dielectric Strength of Polymeric Cable Insulation for Dynamic DC Voltage Stresses

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ABSTRACT

This paper proposes requirements of dynamic stress testing through laboratory scaled experiments for verifying the associated withstand capabilities of HVDC cable systems. The proposed requirements focus on stresses that exhibit slow rate of rise and even slower discharges, as well as oscillatory transient voltages. The paper discusses the testing concepts, taking into account existing standard testing layouts, and examines prospective test waveforms. It also outlines the requirements for defining and measuring test voltages. Furthermore, the paper suggests incorporating dynamic stresses as a technology verification test, along with classical design verification and long-duration tests of HVDC cable systems.

Keywords: transient overvoltage, polymeric cable insulation, laboratory test bench

INTRODUCTION

The statutory priority of underground cables for HVDC land transmission in Germany as well as the growing pan-European need to connect offshore wind parks with HVDC to the onshore grid require robust and reliable HVDC cable systems. In order to prove withstand capabilities against dynamic stresses occurring in fault situations such as during pole-to-ground fault, pole-to-pole fault or faults on the AC side, transmission system operators define additional quality requirements that are not covered yet by international standards.

At present, non-conventional voltage profiles are introduced as part of technology tests that are intended to simulate possible fault voltages [1]. The test recommendations require project specific testing parameters depending on the fault location in the HVDC system, length and system configuration [1,2]. In order to define test parameters and voltage waveshapes that can act as benchmark values, understanding the effects of dynamic voltage stresses on the insulation system of HVDC cable system components is needed.

For this purpose, three testing circuits aiming at creating different prospective test voltage profiles in the high-frequency range were designed, parametrized and built. The basic setup of the test circuits was presented in the past [3]. These arrangements serve as basis to experimentally study the performance of aged and unaged model cable samples against transient voltages superimposed on the nominal DC voltage.

In this paper the influence of two different voltage waveshapes on the failure behaviour of non-aged HVDC cable samples are investigated. A very slow front transient overvoltage (VSF TOV) superimposed on the rated DC voltage, to represent the fault event of symmetrical monopolar and rigid bipolar faults [2,4]. The second arrangement creates a zero-crossing damped transient overvoltage (ZCD TOV) that follows after a breakdown of the rated DC voltage, which is considered representative for voltage reversals occurring at the faulty cable end [2].

At first the model cable is presented including technical justification. An overview of the investigated voltage waveshapes is given including the testing methodology followed by the results of the investigation.

MODEL CABLE

This paper proposes an experimental methodology to analyse the dielectric breakdown mechanisms of TOVs. In addition to the voltage waveform, other parameters will be under investigation during the course of the test series. In particular, the influence of the temperature of the cable and of electro-thermal stress on the dielectric strength will be investigated. In order to achieve a high number of test series, a suitable test object design is required. In this research, an XLPE insulated model cable is utilized as a simplified version of a real cable for testing and investigation purposes. The model cable is designed to represent the electrical and mechanical properties of the actual cable in a laboratory setting. The purpose of using a model cable in this research is to test the behavior of cables under different conditions and study the impacts of various environmental factors on cable performance. Such a use of model cable enables the consideration of actual extrusion conditions along with the influence of semiconducting layers on conduction.

Extruded DC polymeric cables require extremely low conductivity (high resistance) insulation for electrical field distribution. A sufficiently low conductivity ensures stable steady state DC and avoids thermally triggered failures while maintaining low dielectric losses [5]. Non-isothermal conditions due to ohmic losses in conductor caused by the load current develops a temperature gradient across the DC insulation. This further influences the stress regions caused by electric field across the insulation diameter. In an AC extruded insulation, the permittivity of the dielectric is responsible for setting the required electric field, which is capacitively graded and completely defined by Laplace stress. On the contrary, in DC insulation system once the initial transient following energisation reaches a steady state, redistribution of field occurs based on the density of charges defined by Poisson's equation [6].

The design of the model cable takes into account the field distribution across the polymeric insulation and the ratio of the outer to inner radius, since the insulation thickness