Transient thermal phenomenon in HVDC extruded cables under test and operating condition – numerical simulation and measurements

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ABSTRACT

HVDC extruded cables are tested under specified conditions to verify the performance under different load cases in the real application. Main parameters are the applied voltage, conductor current, the operating temperature and the temperature gradient across the insulation during operating condition. In test conditions, it is difficult to meet all these parameters with just one test setup. For that reason in real test setups, the temperature gradient and the heating current often exceed the nominal values. The test remains valid as long as the test parameters are equal or more severe than the specified values. In this paper it is shown, what boundary conditions can be applied to meet the test requirements without additional risks for the test performance.

KEYWORDS

HVDC; extruded cables; SPICE; Type test; PQ test; thermal simulation

INTRODUCTION

Due to the temperature dependency of the DC conductivity of extruded insulation materials, the test and operation conditions need to be carefully selected with respect to their thermal impact. The thermal environment has an influence on field enhancement resulting from the thermal gradient in the insulation and on the electro-thermal stability of the system. Optimizations in the thermal setup of the test loop to reduce the temperature gradient during test condition, can lead to premature electro-thermal instability. The so called “thermal runaway” may occur in a special thermal environment at certain voltage, where for the same voltage the system may remain stable, when the thermal boundary conditions are selected differently.

Common practice of temperature control during HV cable testing is the parallel operation of two cable loops, where one loop is used as thermal reference and is equipped with temperatures sensors on the cable surface and the cable conductor, while the cable loop under voltage is monitored for surface temperature only.

In this paper a SPICE (Simulation Program with Integrated Circuit Emphasis) model is presented, which simulates the thermal behavior of both loops. The network simulating the loop for temperature monitoring consists in resistors and capacitors simulating the thermal properties of the cable and the cable environment as well as the heating source from conductor heating. The model of the loop under voltage consists in a parallel network in the structure as above to simulate the thermal behavior, and a parallel network, which simulates the electrical field distribution and leakage current in the insulation. The electrical network and the thermal network of the cable loop under voltage are linked to each other via power loss density from leakage current and temperature influence on conductivity.

To meet the thermal temperatures specified in the test conditions as much as possible, the loop might be equipped with thermal insulation around the cable. Another degree of freedom is the ambient temperature. Active heating of the cable from outside is a possible method to decrease the temperature gradient for a given conductor temperature and given ambient temperature, but in some test specifications active heating of the cable sheath is not listed as an allowed test condition.

Different methods of applying thermal insulation and temperature monitoring during qualification tests are compared with respect to their risk of premature thermal instability and their influence on field enhancement from temperature gradient.

Temperature measurements on real test setups of 320kV cable system are compared with the simulation results. Insulation leakage current is evaluated based on leakage current measurement and thermal observations on the test cables under voltage. The insulation conductivity is calculated back from the measurements on the cable section and compared with material properties determined on small scale samples.

With the calibrated model from this observation typical cable installations are simulated with respect to thermal behavior and risk of thermal instability.

TEMPERATURE CONTROL FOR HVDC VOLTAGE TESTS

Common practice in HV cable testing is the use of two cable loops with the identical cable, both heated in the same way with electric current in the conductor. One loop is a short loop without high voltage accessories, which acts as thermal reference only (hereafter called dummy loop), and one loop is installed with the high voltage