The Study on the Transient Electric Field Distribution of HVDC Cable

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ABSTRACT

The conductivity is the main factor determining the electrical field distribution in HVDC cable insulation, and it is sensitive to the electric field and temperature. So the electric field distribution in HVDC cable must depend on the structure, applied voltage and temperature. Taking the typical structure of 320 kV HVDC cable as an example, the steady-state and transient electric field distribution under the different temperature gradients with different nonlinear properties of insulation were studied at 1.4 U_0 and polarity reversal voltage with the software of COMSOL Multiphysics. The results show that the insulation utilization coefficient is getting lower while the temperature gradient is getting higher， and that the transient insulation utilization coefficient at the process of polarity reversal voltage is significantly lower than the steady-state insulation utilization coefficient, here the insulation utilization coefficient is defined as the ratio of the average electric field and the maximum electric field. It is strongly recommended that the problem of transient electric field distribution must be considered seriously at HVDC cable insulation materials research and insulation structure design.

KEYWORDS

HVDC cable, transient electric Field, temperature gradient, insulation utilization coefficient

INTRODUCTION

During the running of HVDC cable, the temperature of the insulation near the conductor will rise for Joule-heat caused by load current, while the temperature of the outside cable insulation is relatively low, thus the temperature gradient will form in the cable insulation.

The steady-state field distribution of the insulation under DC voltage depends on material conductivity, while the conductivity is a function of temperature and electric field[1]. So the temperature gradient effect will affect the conductivity and then affect the steady-state field distribution in the cable insulation. Meanwhile, the temperature gradient effect on the injection and accumulation of space charge will affect the electric field distribution[2].

When the cable has just been put into operation and the voltage polarity reverses, the transient electric field distribution in the cable insulation will be more complicated due to the nonlinear conductivity of insulation materials which is related with temperature and electric field[3,4,5].

Therefore, it is significant for the materials' development and the structural design of HVDC cable to research the effect of insulation material nonlinear conductivity and temperature gradient on the steady-state and transient electric field of cable insulation.

In this paper, the effect of the insulation materials nonlinearity on the steady-state and transient electric field distribution in HVDC Cables under different temperature gradients and different voltage types were analyzed by using the software of COMSOL Multiphysics.

DESCRIPTION OF THE MODEL

The typical structure of 320 kV and 500 MW HVDC cable is taken as research object, as shown in Fig. 1.

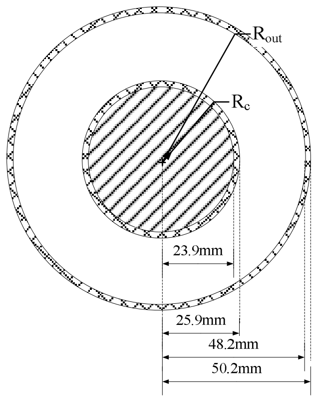

Fig. 1: Typical structure of 320 kV HVDC cable

In this model, the conductor is set to copper, the relative permittivity ε_r of semi-conductive shielding layer is 1000 and its conductivity is 0.01 S/m, the relative permittivity ε_r of the insulating layer is 2.3 and its conductivity is described by

$$\gamma(\mathrm{E,T}) = A\exp\left(-\frac{\varphi q}{k_b T}\right)\frac{\sinh\left(10^6 B|E|\right)}{10^6|E|} \quad [1]$$

where A is polymer-related constant in V/(Ω·m^2), B is the electric field dependence coefficient in m/V, φ is the thermal activation energy of conductivity in eV, q is the electron charge(1.602*10^{-19}C), k_b is Boltzmann's constant(1.38*10^{-23} J/K), T is the temperature in Kelvin and E is the electric field in kV/mm.

The temperature of outside insulation is set to 40 ℃ in this paper, temperature gradient(0~50℃) is achieved by changing the temperature of the core conductor. The temperature of cable insulation is determined by

$$T(r) = T_c + \frac{(\ln r - \ln R_c)\cdot(T_{out} - T_c)}{\ln R_{out} - \ln R_c} \quad [2]$$

here R_c and R_{out} is the radius of inner edge and outer edge of the cable insulation, r is the radius of any place in the cable insulation, T_c and T_{out} is the temperature of the conductor and outside edge of the cable insulation, $T(r)$ is the temperature of r position.

The effect of voltage polarity reversal time on the electric field distribution was studied by changing Δt. The voltage waveform is shown as Fig. 2.