Electro-thermal simulation methodology for HVDC cable GIS termination

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ABSTRACT

The interconnection between HVDC cables and Gas Insulated Substations (GIS) technology is becoming an essential part to complete the HVDC transmission systems. Under DC voltage the electric field is complex to simulate as it is influenced by charge accumulation phenomena and by materials conductivities, which again depend on electric field and temperature. The coexistence of different insulating materials coupled with the thermal gradient, makes harder the prediction of the electric field distribution. This paper presents a simulation methodology that can be used to evaluate the electric stresses in GIS/cable termination under different operating conditions including polarity reversal and superimposed impulses.

KEYWORDS

HVDC, Cable/GIS termination, modelling, conductivity, field distribution, space charge, surface charge

INTRODUCTION

With the integration of renewable energy in power generation and the development of interconnected network, HVDC technology is becoming more and more important in the energy transmission. HVDC cables play a fundamental role in offshore renewable energy integration and interconnections [1]-[3]. Moreover developments in HVDC GIS is of great interest for offshore power generation due to its compactness and its potential for increasing reliability and interconnectivity. The interconnection of cables with the Gas Insulated Substations (GIS) technology is therefore an essential part to complete the HVDC transmission systems [4].

Mastering the electric field distribution is a key element in high voltage insulation design. Unfortunately, under DC voltage application, the electric field distribution is more complex to predict as the field depends simultaneously on the permittivities and conductivities of the insulating materials. Indeed the field distribution during DC application is changing over time between different state, capacitive, transient and resistive, and it is hard to predict in advance which state is the worst case for the system. It is well known that the conductivity of an insulating material depends on the electric field and the temperature. This means that the electric field will change depending on operating conditions [5]. The evaluation of the electric stresses during all the possible states is mandatory for design and for identification of weak point. Additionally, accumulation of charge inside solid materials (space charges) and on the interfaces between different materials (surface charges) also play an important role in electric field enhancement and should be integrated in the evaluation [6]. The electric field study on cable/GIS terminations is particularly challenging compared to HVDC GIS/GIL or HVDC cables due to the complex geometry with coexistence of several insulating materials with different material properties.
This paper presents a simulation methodology to evaluate the electric stress of a HVDC cable/GIS termination under different operating conditions taking into account all the materials properties and their dependence on temperature and electric field. The effect of surface and space charge accumulation on the electrical field intensification in case of polarity reversal and superimposed impulse tests is as well considered.

PHYSICAL BACKGROUND

During DC voltage application the electric field is firstly capacitive and then turns into a resistive field. The transition time is depending on the conductivity of the insulating materials (gas and solid) and can vary between few minutes to weeks [7]. The governing equations under DC voltage application are:

$$j = \sigma E + \frac{\partial D}{\partial t} \tag{1}$$

$$\nabla \varepsilon_0 \varepsilon_r E = \rho \tag{2}$$

$$\nabla j = -\frac{\partial \rho}{\partial t} \tag{3}$$

Where j is the current density; σ is the conductivity of material; D is the electric flux density, E is the electric field, ε_0 and ε_r are respectively the vacuum permittivity and the relative permittivity and ρ is the space charge density.

Due to the exponentially conductivity dependence on temperature according to the Arrhenius law, a temperature gradient generates a conductivity gradient that results in a space charge distribution in the insulating material [8].The electric field profile and space charge associated with the temperature gradient can be calculated through (4) and (5), respectively, once the activation energy, E_a, and the temperature (T) profile are known [9].

$$E(r) = E_0 \frac{r_0 \sigma_0}{r \sigma(r)} \tag{4}$$

$$\rho_{tg}(r) = -\varepsilon_0 \varepsilon_r E(r) \frac{E_a}{kT^2} \frac{dT}{dr} \tag{5}$$

Note that these equations are valid under the assumption of Ohmic regime, i.e. neglecting other space charge accumulation phenomena as charge injection from electrodes and ions generated by electro-dissociation.

STUDY CASE

HVDC Cable/GIS geometry

The dry-type HVDC cable/GIS termination studied in the simulations is an "inner cone" termination type as shown in Fig. 1. Due to the rotational symmetry of the cable and the termination the simulations were performed with a 2D axisymmetric component. The different insulating materials used in the termination are numbered in Fig. 1 and detailed in Table 1. The choice of these materials should be considered as indicative for the simulation purpose.

All the simulations were carried out using COMSOL Multiphysics software. This software is able to combine the