Influencing factors on field inversion in HVDC cables

Karsten **FUCHS**, Frank **BERGER**; Technische Universität Ilmenau, Germany, karsten.fuchs@tu-ilmenau.de, frank.berger@tu-ilmenau.de

Andreas **FISCHER**, Dietmar **DRUMMER**; Institute of Polymer Technology, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany, fischer@lkt.uni-erlangen.de, drummer@lkt.uni-erlangen.de

ABSTRACT

In HVDC cables an electric flow field is reached in steady state, which depends on the joule heating effect of the inner conductor and the resulting temperature-dependent electrical conductivity of the insulation material. As a result, the effect of field inversion is caused by a reversal and an enhancement of the electrical field strength in the insulation material from the inner to the outer conductor and limits the maximum loads (currents) of HVDC cables. Therefore, the focus lies on influencing factors to minimize the field enhancement in HVDC cables and to increase the inner conductor current. For such research, electric field strength distributions are calculated with numerical simulations for XLPE-HVDC cables in dependence on space charge density, inner conductor current and thermal conductivity.

KEYWORDS

Extruded HVDC Cables, Cable Insulation, DC Electric Field Inversion, Temperature- and Field-Dependent Phenomena, Thermally Conductive Polymers

INTRODUCTION

The integration of renewable energy and thereby the required transmission of more and more energy over long distances have caused an increase in transmission capacity in Europe. As such focus must also be placed on High Voltage Direct Current (HVDC) systems. [1]

HVDC systems are established either by thyristor-based line commutated converter technology (LCC) or insulated-gate bipolar transistor (IGBT) technology (VSC). VSC technology is preferred for installation of a DC network in Germany, because extruded cables of cross-linked polyethylene (XLPE) can also be used as a possible transmission medium [1]. However, a nonlinear, radial, electrical conductivity distribution and the accumulation of space charges in the insulation are disadvantageous. These effects occur during operation in accordance with the electric field strength and the thermal energy because of the nominal voltage and nominal current of the inner conductor.

With the changed electrical conductivity and space charges, both effects lead to a reversal and an increase of the electric field strength maximum (field inversion) and a field reduction near the electrodes [2]. Therefore, the maximum transmitted power of extruded HVDC cable amounts to $1\,GW$ with a nominal voltage of $320\,kV$ and an inner conductor current of about $1.5\,kA$ (Inelfe interconnection [3]).

To improve HVDC cables´ transmission power, either nominal voltage or current can be raised to reach a comparable current as in overhead lines (about $2\,kA$ for VSC technology). For instance, ABB represents a new 525 kV HVDC XLPE cable system [4]. Therefore, XLPE had to develop for complying with lower electrical conductivity and, consequently, lower space charge accumulation at a voltage higher than $320\,kV$.

In contrast, this paper focuses on evaluating fundamental research aimed at increasing an inner conductor current with the same voltage ($320\,kV$), without exceeding the permissible inner conductor temperature of $70\,°C$. Firstly, a fundamental understanding of the physics behind this research is pursued. Furthermore, a calculation of the electrical field strength distribution in common XLPE HVDC cables is presented to evaluate the behaviour of these cables during operation (at $320\,kV$ and $1.5\,kA$ [3]). On this basis, the impacts of a higher thermal conductivity (and nearly unmodified electrical conductivity) and space charge density distributions on the electric field strength are observed fundamentally by means of numerical simulations. Furthermore, the means by which to accomplish higher thermal conductivity with nearly unmodified electrical conductivity in thermally conductive polymers comprises the subsequent section of this research. For this, the requirements and selection of electrical isolating filler particles are discussed. In addition, we elucidate the fundamental effect of the filler particles on heat dissipating with higher thermal conductivities. The advantage of this approach is the reduction of the electric field strength by lower temperature gradients in the insulation material. As a consequence, we evaluate whether the transmitted power of HVDC cables can be significantly improved through this research.

PHYSICS BEHIND THIS RESEARCH

The stress of a single-core extruded XLPE-HVDC cable with a nominal voltage U_0 and nominal inner conductor current I_0 affects the electric field strength $E(r)$ and the temperature distribution $\vartheta(r)$ (see **Figure 1**).

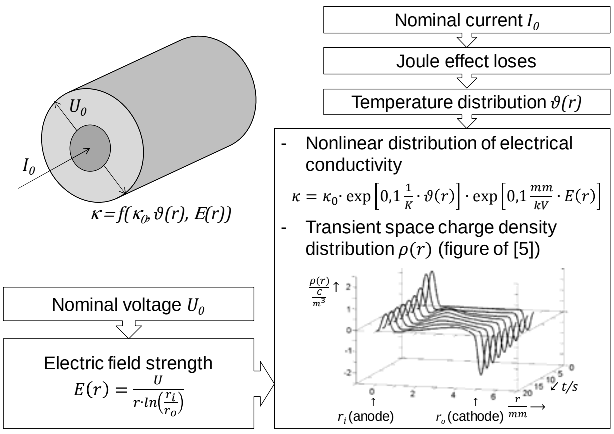

Figure 1: Stress of extruded HVDC cables in operation