Modeling of DC cables for transient studies

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ABSTRACT

The development of DC systems goes along with an increasing demand for electromagnetic transient simulations involving DC cables. These are generally represented by simple or AC cable models. As a result, physical phenomena specific to DC cables are omitted. In this paper, the impact of temperature and field dependent conductivity on the telegrapher's equations is studied, starting from Maxwell's equations. With this approach, it is shown that the telegrapher's equations cannot be solved as they are currently in EMTP-like programs. However, it seems still acceptable in most cases to use existing EMTP models for transient studies involving DC cables, if a few changes are carried out.

KEYWORDS

HVDC, modeling, transients.

SYMBOLS

1	Subscript referring to the core
2	Subscript referring to the insulation
3	Subscript referring to the metal screen
4	Subscript referring to the oversheath
B	Magnetic flux density
ΔT	$T_2 - T_1$
E	Electric field
ε	Dielectric permittivity
g	Electric conductivity
γ	Propagation constant
H	Magnetic field
I_c	Current in the core
I_s	Current in the metal screen
$\vec{J}$	Current density
μ	Magnetic permeability
ω	Angular frequency
r	Radius
ρ_q	Electric charge density
T	Temperature
T_1	Temperature of insulation inner face
T_2	Temperature of insulation outer face
V_c	Electric potential of the core
V_s	Electric potential of the metal screen
Y	Admittance matrix
Z	Impedance matrix

INTRODUCTION

The electrical modeling of AC underground single-core cables is a topic that has been quite well addressed. Accurate models are available and are suitable for steady-state as well as transient studies.

The development of DC systems goes along with an increasing demand for electromagnetic transient simulations involving DC cables. These are generally represented by simple models or AC cable models. As a result, physical phenomena specific to DC cables are omitted, which may be detrimental to calculation accuracy.

Transmission line modeling involves deriving the telegrapher's equations, which govern voltages and currents in conductors, from Maxwell's equations, which describe the propagation of the electromagnetic field. This is what is behind the models commonly used in EMTP-like programs. Can these models be used to represent DC cables?

SPECIFICITIES OF DC CABLES

DC cables behave differently than AC cables because of space charges. These are distributed within the insulation and come from the migration and trapping of electrons, holes or ions. This phenomenon occurs from the following processes [1]:

- Orientation of dipoles under the influence of the electric field;
- Injection of charges at interfaces;
- Ionization of impurities within the material.

Space charges influence the electric field within the insulation. Hence, it is considered that the insulation conductivity varies with temperature and electric field. This makes the computation of the latter much more difficult.

EXISTING WORK

Several formulae for insulation conductivity can be found in the literature, taking into account the temperature and electric field dependency.

Many works use these formulae to compute the electric field in steady state and assess the behavior of the insulation in response to voltage steps. For example, reference [2] presents the calculation of the electric field under different operating conditions: voltage raise, stable stage, polarity reversal, etc.

Also worth mentioning is reference [3], which proposes a way to improve the accuracy of models at DC and low frequencies by modifying the series expansions of the characteristic admittances and propagation functions.

MATHEMATICAL MODEL

The aim here is to see to what extent a non-uniform conductivity $g(T,E)$ and a non-zero charge density ρ_q would modify the cable modeling in EMTP.

Electrical modeling is to establish and solve the telegrapher's equations:

$$-\frac{\partial}{\partial z}\begin{pmatrix}V_c\\V_s\end{pmatrix} = Z\begin{pmatrix}I_c\\I_s\end{pmatrix} \qquad (1)$$

$$-\frac{\partial}{\partial z}\begin{pmatrix}I_c\\I_s\end{pmatrix} = Y\begin{pmatrix}V_c\\V_s\end{pmatrix} \qquad (2)$$