Modeling of electromagnetic transients in long HVDC cable systems

Luigi **COLLA**, Prysmian Group, (Italy), luigi.colla@prysmiangroup.com,

ABSTRACT

This paper describes the application of Finite Sections Modeling to HVDC cable systems. A first part provides information on some key parameters relevant to correct model implementation. Individual cable layers can be modelled with passive ladder networks having a number of elements needed to achieve the desired accuracy.

A real cases of a long HVDC cable system has been studied to validate the model transient performance against recorded short circuit events.

In a second part finite section modelling is also applied to calculate the electrodynamic force between two cables during short circuit. This is of interest when cables are to be installed in tunnel, where they are typically spaced in air by means of supporting structures.

KEYWORDS

Submarine cable; Finite Sections Modeling; Continued Fractions; HVDC; EMTP, Transient, Gibbs, Validation.

INTRODUCTION

The design of long HVDC cable systems requires detailed electromagnetic transient studies to identify and address potential risks and to properly validate the design by means of testing [1] [2]. Accurate and reliable models are needed to this purpose: however, while frequency-domain modeling is well established, time-domain simulation of power cables in the frequency range of interest to power system transients, i.e. from dc to 1 MHz still poses difficulties. Modal analysis techniques with constant transformation matrices, successfully applied to overhead lines, are less suited to underground cable systems on account of the strong frequency dependence of transformation matrices. Other models accounting for frequency dependence of transformation matrices and based on fitting techniques may suffer numerical instability due to computation (truncation) errors, unstable poles fitting of the transfer matrix and interpolation errors on modal time delays that are not in general integer multiples of the simulation time step in EMTP- like software. Numerical instability can occur especially in simulation of transients involving frequencies between dc and some kHz.

This paper deals with the application and extension of the “Finite Sections” (FS) method proposed in [1] and further developed in [2], that is, cable modeling by means of cascaded cells taking explicitly into account the frequency dependence of conductors and ground impedances. The result is a multi-conductor model, suitable for both time and frequency domain, made of passive elements and coupling transformers inductive arrays only, directly obtained by physical-geometrical data, ruling out non-passive realizations and numerical instability. The number of model elements can be increased to meet the required bandwidth and accuracy, which practically is not a limit for usual power system transient studies; dc operation and trapped charge do not pose problems. Features such as dielectric losses, semicon layers, ferromagnetic armour and pipe/tunnel installation are straightforwardly incorporated in the model.

This paper focuses on some study cases of long HVDC cable systems where voltage and current transients have been calculated on conductor and metallic screen in case of faults. In the paper the calculated quantities are compared against measured ones during operation of cable systems.

CABLE MODELING

“Finite Sections” (FS) method [1] [2], has been used in the studies dealt within this paper. In essence the cable is modeled by means of cascaded cells taking explicitly into account the frequency dependence of conductors and Earth impedances. The result is a multi-conductor model, suitable for both time and frequency domain, made of passive elements and coupling transformers inductive arrays only, directly obtained by physical-geometrical data, ruling out non-passive realizations and numerical instability. The number of model elements can be increased to meet the required bandwidth and accuracy, which practically is not a limit for usual power system transient studies; dc operation and trapped charge do not pose problems. Features such as dielectric losses, semicon layers, ferromagnetic armour and pipe/tunnel installation are straightforwardly incorporated in the model.

Further to the description already provided in [1] and [2] within this paper some interesting improvements have been achieved in terms of modelling, validation and electrodynamic forces calculations.
An example drawing of a HVDC cable dealt with in this paper is shown in Fig.1

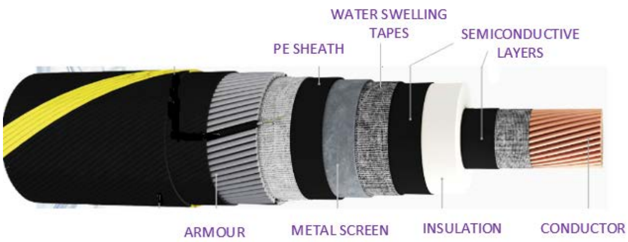

Fig. 1: Drawing of a HVDC submarine cable

<u>Selection of cells length</u>

A traditional criterion states that the Pi cell length should be lower than $\lambda/10$, being λ the shortest wavelength of the transient phenomenon to be studied.

In case of faults transmission HVDC lines typically discharge with a damped oscillatory transient. The frequency of this transient depends on line length and its electrical parameters, including in principle also converter components electrical parameters.

The free oscillating frequency for a distributed parameter single-phase line short circuited at one end can be calculated according to the following formula: