Sensitivity Analysis on Design Parameters of Extruded HVDC Cables for Traveling Wave Propagation and Fault Localization Studies

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ABSTRACT

This paper examines the influence of design on the wave propagation properties of 525kV HVDC cables, highlighting the significant impact of the cable design on such characteristics. The sensitivity analysis based on a conventional analytical approach shows that the thickness of the main insulation and semiconducting layers are the most important parameters influencing the wave propagation properties of the coaxial modes. Ultimately, the results of this study underscore the critical role that cable design plays in shaping wave propagation characteristics.

KEYWORDS

HVDC; XLPE; Power cable; Sensitivity analysis; Electrical design; Transients, Wave propagation; Fault localization

INTRODUCTION

Extra long HVDC cables with voltage ranges of 525 kV and lengths spanning hundreds of kilometers are becoming increasingly popular for new HVDC projects. Given their extensive usage, it is crucial to implement accurate online fault detection and fault localization. Traveling-wave-based protection and fault localization methods heavily rely on high-frequency wave propagation characteristics, largely impacted by the HVDC cable design [1]. A comprehensive understanding of the wave propagation characteristics and their sensitivity to design parameters is necessary to effectively design such protection algorithms. Therefore, this paper provides an in-depth sensitivity analysis of the wave propagation characteristics of the main cable parameters.

Several modeling approaches have been developed in the literature for cables, each tailored to specific applications. However, these models may have limitations in terms of their accuracy to handle various electromagnetic effects, such as skin and proximity effects, conductor coupling, electromagnetic interference, dispersion, and details of soil modeling and return paths [2, 3, 4, 5, 6]. Notably, the MoM-SO method by Patel was verified against the finite element method (FEM) and proved higher accuracy compared to the analytical methods, as it accounts for skin, proximity, and ground return effects together.

The present study explores analytical formulas to calculate the cable per unit length impedance and admittance, propagation velocity, and attenuation constant [7]. These formulations consider the skin effect and ground return but not the proximity effect. By varying the inputs to these formulas, a sensitivity analysis is carried out on HVDC cable design parameters, including cable configuration, core, sheaths, semiconductors, and insulation layers. The sensitivity analysis provides insights into those input parameters that have the greatest impact on cable propagation characteristics, specifically wave propagation speed and attenuation constant.

First, the cable system configuration is presented, with modelling assumptions. Then, a short explanation of the analytical formulas to calculate the wave propagation characteristics is provided. Furthermore, the case studies and the results are presented. Ultimately, the paper aims at determining the most critical parameters to consider in designing traveling-wave-based protection methods and specifying the required modeling choices.

CABLE SYSTEM CONFIGURATION

In the industry, monopolar and bipolar cable configurations with or without a Metallic Return (MR) are commonly used for power transmission. As demand for higher power transmission increases and voltage levels shift higher, the bipolar configuration is becoming more popular and is therefore used as the base case for this study. To analyze the difference between wave propagation in the pole and MR cables, a dedicated MR cable is considered. An HVDC cable configuration typically consists of multiple layers for electrical, mechanical, or environmental considerations, as illustrated in Figure 1 and 2. For submarine HVDC cables, at least three conducting layers and three insulating layers are typically used. Additionally, these configurations often include fiber optic cables integrated within the cables or as a separate cable, but this study does not consider them.

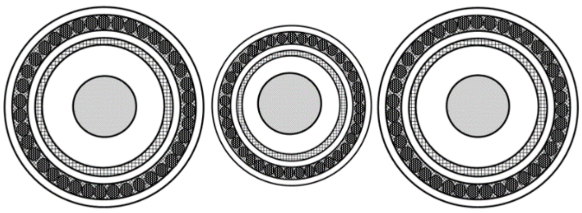

Figure 1. HVDC cable configuration- Horizontal bipolar with MR in the middle