Capacitive and Inductive Coupling in Cable Systems – Comparative Study between Calculation Methods

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ABSTRACT

A numerical investigation is performed between different methods used for the calculation of sheath currents and voltages at power frequency. A typical underground cable system is considered, examining both capacitive and inductive coupling using FEM analysis, EMTP-like software, and CIM method. Results from all three approaches are in very good agreement, validating the accuracy and applicability of the presented methodologies.

KEYWORDS

Cable system, capacitive coupling, complex impedance matrix (CIM), electromagnetic transient program (EMTP), finite element method (FEM), inductive coupling.

INTRODUCTION

In the process of designing cable systems, several issues are related to the electromagnetic interference (EMI) and especially to the capacitive and inductive coupling between conductors and sheaths. EMI is associated with the current rating calculation, where the power losses on cable sheaths during normal operation must be taken into account [1]. EMI problem is also related to the calculation of overvoltages on cable sheaths, which should be kept under acceptable limits satisfying health and safety standards [2].

The calculation of voltages and currents in the abovementioned scenarios can be performed using a variety of methods, mostly depending on the tradeoff between the accuracy and computation burden. The three most common numerical approaches are: the Complex Impedance Matrix (CIM) method, a numeric solution based on the self and mutual impedances of the cable system taking into account the inductive coupling; the ElectroMagnetic Transient Program (EMTP-like) software, using distributed impedances and admittances for the modeling of the cable system and relevant surrounding, which also takes into account the capacitive coupling of the cable system; and the finite element model (FEM) which effectively replaces telegrapher's equations with the formulation of the generic electromagnetic problem. Since all these methods are used in various design studies performed by cable engineers, there is a need to investigate their applicability at different stages of the design process.

This paper performs a systematic numerical investigation of different methods used for the calculation of sheath currents and voltages at power frequency, with the purpose of highlighting their suitability in terms of accuracy and ease of use. The considered models include CIM method [2], ATP/EMTP software [3], and COMSOL Multiphysics® FEM [4]. Without loss of generality, a typical high-voltage underground cable configuration is employed and all classical bonding types are examined; that is, solid-, single-point and cross-bonding types. In addition, both capacitive and inductive couplings are considered. For the former, ATP/EMTP is compared to COMSOL, while CIM is not used since it cannot take into account the cable charging current. For the latter, i.e., the inductive coupling, results derived from all methods are presented in terms of sheath voltages and currents.

Results in all cases are in very good agreement, validating the applicability of the abovementioned models. It is concluded that CIM is the most straightforward approach, limited though for cases of inductive coupling. On the other hand, the EMTP-like software can be used taking into account both capacitive and inductive coupling for most typical cases. In more complicated geometries and configurations, FEM can be employed solving the generic electromagnetic formulation.

SYSTEM UNDER STUDY

An underground cable of nominal voltage 87/150 kV and cross-section 1000 mm^2 is examined. The cable follows the design of Fig. 1, where the various layers are indicated. Their properties, including the surrounding media, are given in Tables A.I-A.III in the Appendix. The whole model is assumed to be infinitely long in the cable axis direction, neglecting any end effects so as to render the 2D analysis sufficient. Considering sheath bonding types, the most commonly used in transmission systems are examined. These include: solid-bonding, single-point-bonding, and sectionalized cross-bonding.

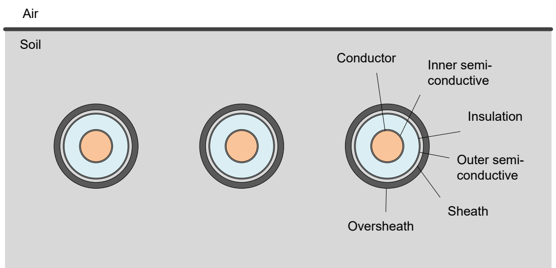

Fig. 1: Indicative cable configuration.

CALCULATION METHODS

The sheath currents and voltages can be calculated using