Review of underground cable impedance and admittance formulas

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A number of underground cable transmission systems are under construction and/or are planned in many countries, and active investigations related to the cables have been carried out by CIGRE WG B1.30 and WG C4.502 an reported in CIGRE Technical Brochures. For the insulation design and coordination of an underground cable, it is essential to predict and investigate possible over-voltages in the cable system. Cable impedance and admittance formulas are necessary to study transient and steady-state phenomena on the cable.

The impedance and admittance formulation of a cable is far more complicated than that of an overhead line, because even a single-phase cable consists at least of two conductors, i.e. a core conductor and a metallic sheath (shield) in the case of a single-core coaxial cable (SC cable). Also a long high-voltage SC cable is quite often cross-bonded, similarly to overhead line transposition. Furthermore, a so-called pipe-type cable (PT cable), such as a POF cable, is composed of three-phase cores installed within a conducting pipe. Then the PT cable becomes a four-conductor system. If the inner conductors are SC cables, the PT cable is a seven-conductor system.

An impedance formula of a cylindrical conductor was derived by Scheluknoff in 1932. The impedance and admittance formulas of an SC cable were developed by Wedepohl and Wilcox. The impedance and admittance formulas of a PT cable, where an inner conductor is eccentric to the pipe centre, were developed by Brown and Rocamora. The earth-return impedance of an underground cable was derived by Pollaczek.

This paper summarizes the impedance and admittance formulation of three-phase SC and PT cables implemented into the EMTP (Electro-Magnetic Transients Program) as a subroutine "Cable Constants" since 1976 in the Bonneville Power Administration, US Department of Energy. Modeling of various cable systems such as cross-bonded and tunnel-installed cables is also explained.

Problems related to the formulation and the impedance formulas have been reviewed, and possible countermeasures are described. Some of the problems come from approximations adopted in the formulation and assumptions made to derive the impedance formulas.

Numerical electromagnetic analysis tools such as NEC (Method of Moments - MoM) and VSTL (Finite Difference Time Domain - FDTD) are explained as a solution for the problems reported in this paper. However, these methods require large memory and CPU time, and their accuracy is heavily dependent on memory size, time step, segment length (in NEC) and cell size (VSTL).