[[1]](#footnote-1)

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## Frequency-dependent soil model

The macroscopic electromagnetic behavior of soil is determined by its multiphase particulate nature, that is, by the interaction of its constituents and their individual properties. Regarding electromagnetic problems, the behavior of soil (dispersive lossy dielectric material) can be described via two quantities: the relative permittivity, ε*rg*, and the conductivity, σ*g*. These quantities are frequency-dependent due to dynamic polarization processes as opposed by inertia. The exact value of DC conductivity is also required for a complete electromagnetic characterization so as to discern between the contribution of polarization and conduction losses; however, this is not necessary for dealing with electromagnetic problems. A more detailed account on the electromagnetic behavior of soil has been given in [15].

The electrical properties of soil (ε*rg* and σ*g*) can be predicted using models appropriate for engineering applications; these models describe the variation of ε*rg* and σ*g* with excitation frequency. Several FD soil models applicable to the switching and lightning transients frequency ranges have been proposed in literature [12], [16]. In this paper, the Longmire and Smith (LS) [13] and the CIGRE WG C4.33 [17] soil models were adopted based on the discussion of [12]. The former model is based on laboratory measurements (*f*: 100 Hz – 200 MHz) and was verified through circuit analysis. The latter was derived on the basis of field tests (*f*: 100 Hz – 4 MHz).

According to the LS soil model, ε*rg* and σ*g* (S/m) are estimated as [13]

, (6)

 (7)

where *f* (Hz) is the frequency, *εr*g*,∞* is the high-frequency (HF) relative permittivity of soil (equal to 5 according to [13]), *an* (p.u.) are empirical coefficients given in Table 1 of [13], and *fn* (Hz) are scaling coefficients [16] calculated as a function of theDC soil conductivity, *σ*g*,DC* (S/m).

. (8)

The corresponding ε*rg* and σ*g* (S/m) expressions for the CIGRE model are [17]

, (9)

 (10)

where *σ*g*,LF* (S/m) is the soil conductivity at 100 Hz.

It is noted that, according to common practice, the low-frequency (LF) soil conductivity *σ*g*,LF* (typically at 100 Hz) and the HF relative permittivity *εr*g*,∞* (1 MHz or higher) are used where frequency-independent (constant) soil electrical properties are adopted.

In this study, nine soil cases are investigated:

1. three cases with constant soil properties (CP) (σ*g*, ε*rg*): (0.01 S/m, 15), (0.001 S/m, 5), and (2·10−4 S/m, 3).
2. three FD cases adopting the LS soil model [13]
3. three FD cases adopting the CIGRE soil model [17].

For the six FD cases: σ*g,100Hz* = 0.01, 0.001 and 2·10−4 S/m. The investigated LF conductivity values correspond to soil resistivities of 100, 1000, and 5000 Ωm, covering a wide range of soils commonly found in real world installations [32].

## System configuration

Fig. 2 shows the cross-section view of the investigated configuration, which comprises an overhead transmission line sharing the same right-of-way with an aboveground pipeline. More specifically, the interfering system is an 150 kV single-circuit overhead line with phase conductors in flat formation and two ground wires. The interfered system is a metallic gas/oil coated pipeline installed at a height of 1 m above ground at a horizontal distance of 10 m from the overhead line. Fig. 2 depicts the cross-section and electromagnetic properties of the pipeline. It is noted that the latter has been used in interference investigations before [].

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