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Surge and energization tests and modeling on a 225 kV HVAC cable

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ABSTRACT

This paper presents experimental results from surge and energization field tests carried out on a 225 kV underground XLPE cable with 64 km and 17 major sections with cross-bonding of sheaths. The surge tests applied a 2 kV surge to minor and major sections having 1080 m and 3952 m, respectively. The tests on the minor section were intended to excite different propagation modes and observe the respective cable responses. In the energization tests, the transient current and voltage at the sending end were measured, when energizing the full cable, from each end. Measured results of current show the impact of transformers in the network and the reactive compensator. The energization tests were simulated in EMTP using detailed and simplified cable models, corresponding to using a separate model for each cable minor section or a homogeneous equivalent for the whole cable length. Computed results show that using the simplified model does not reduce the accuracy of simulations of core voltages and currents, because the simulated test concerned only core conductor quantities.

1. Introduction

Projects of new cable installations have taken place worldwide in the last few years. These cable links are used for intercontinental connections, to reinforce the grid with reduced impact in the surrounding environment, and to connect renewable energy sources to the grid [1–5].

The increase of computer capacity and the improvement of simulation tools allowed the development of more accurate cable models used for electromagnetic transient (EMT) studies, cable fault location and harmonic studies [6–13]. A cable model can be validated based on simulations only [6–11], but a more reliable validation requires a comparison of the simulation results with measurements from field tests performed on the actual cable system [7,9,13–18].

This paper presents experimental results from field tests carried out on a high-voltage alternate-current (HVAC) cable. Part of these results were previously presented at IPST 2017 [29].

In the surge tests, a 2 kV surge was applied to a minor section and to a major section of the cable having, 1080 m and 3952 m, respectively. The advantage of testing a single minor section is that we can excite each propagation mode separately and observe the respective cable responses, which is useful for model validation. In the energization test, the full 64 km long cable was connected to the grid. The energization test is simulated in EMTP.

2. Characteristics of the cable system

The tested system is a 225 kV XLPE underground cross-bonded cable, with 64 km length, connecting Boutre and Trans stations in France. The cable phases are enclosed by high-density polyethylene (HDPE) tubes embedded in concrete. Fig. 1 depicts the layout of the cable and Table 1 shows the cable data. Both 2000 mm^2 and 2500 mm^2 cables are installed, depending on location. The cable has 17 major sections. The cross-bonding joints of the terminal major sections are protected by surge arresters. Reactive compensators are connected at both cable ends.

The minor and major sections used in the surge tests are represented in Fig. 2.

3. Surge tests

The surge tests were conducted during the cable construction. In these tests a 2 kV 1.2/50 μs surge was applied to a minor and to a major cable sections, having 1080 m and 3952 m, respectively. The generator output impedance is 2 Ω. Grounding rods had to be installed next to the two terminals of the minor section and the

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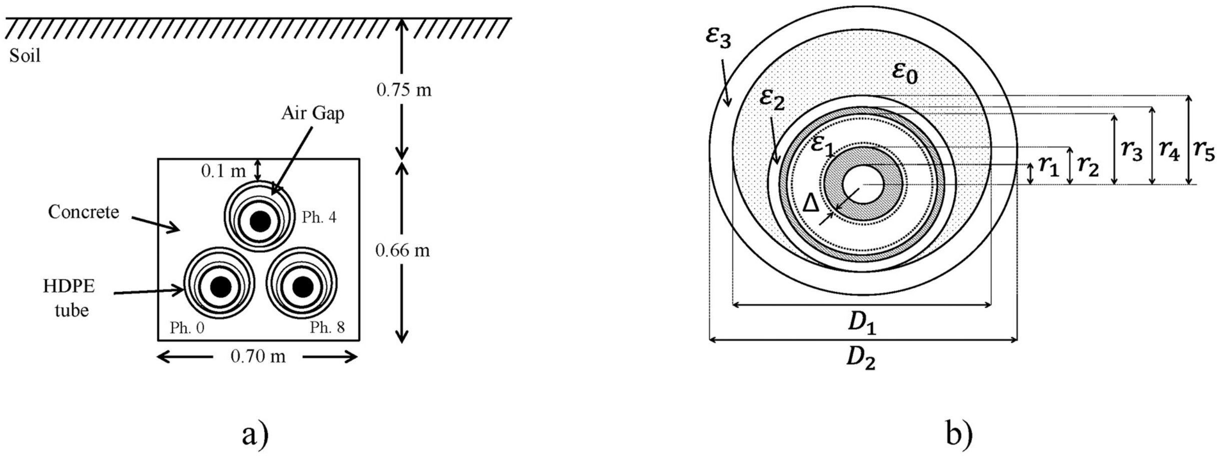

Fig. 1. Layout of the 225 kV XLPE underground cable: a) cable system layout; b) one-phase layout.

Table 1
Data for 225 kV XLPE underground cable.

Parameter	2000 mm² cable	2500 mm² cable
Core cond. ($r_1 = 0$), $\rho = 1.76 \times 10^{-8}$ Ω m	r_{2n} = 34.5 mm[a], r_2 = 28.4 mm[b]	r_{2n} = 37.1 mm[a], r_2 = 31.9 mm[b]
Semicond. screens	Δ = 3 mm (thickness)	
Core insulation	$\varepsilon_{r1} = 2.5$, tan δ=0.0008	
Metallic sheath $\rho = 2.84 \times 10^{-8}$ Ω m	r_3 = 56.4 mm, r_4 = 57.2 mm	r_3 = 59.9 mm, r_4 = 60.7 mm
Outer insulation $\varepsilon_{r2} = 2.5$, tan δ=0.001	r_5 = 62.2 mm	r_5 = 65.7 mm
HDPE tubes	D_1 = 198.5 mm, D_2 = 225 mm $\varepsilon_{r3} = 2.5$, tan δ=0.001	

[a] Nominal radius of core conductor.
[b] Corrected radius accounting for section of wires in the strand.

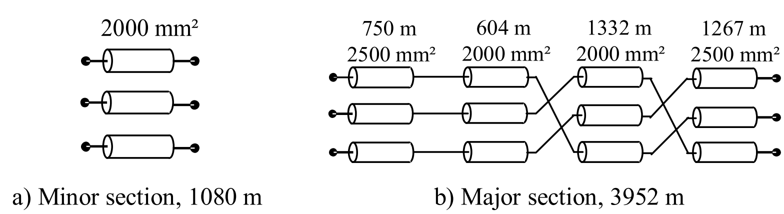

Fig. 2. Minor and major sections used in the surge tests.

receiving end of the major section, for protection of equipment and operators. The major section sending end is at a substation where a grounding network is available. The DC values of grounding resistance are 30 Ω (measured) for the remote areas and 5 Ω (provided by RTE) for the substation.

The tests on the minor section were intended to excite each propagation mode separately and observe the respective cable responses. Therefore, the surge was applied core-to-ground (Section 3.1), core-to-sheath (Section 3.2), two and three-phase inter-sheath (Section 3.3) and sheath to ground (Section 3.4). Several tests were also conducted on the major section. Only the sheath-to-ground surge application is presented here (Section 3.5).

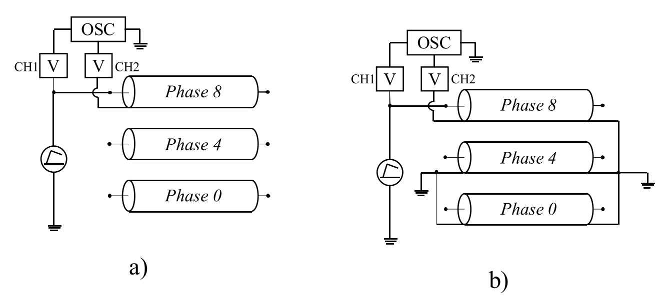

Fig. 3. Field test circuits for core-to-ground surge application on a minor section: a) sheaths open; b) sheaths grounded.

3.1. Core-to-ground surge application on a minor section

The circuits in Fig. 3 were used in the field test for core-to-ground surge application on a minor section. Surge voltage was applied to the core of a minor section and the sheath voltage of the same phase was measured. The two circuits are for the case of all sheaths open-circuited and for the case of sheaths grounded (except the measured sheath).

Fig. 4 shows the measured sheath voltages, for the two cases a) and b). The high waveform attenuation indicates that the mode observed is an earth-return mode. There is also a contribution of a coaxial mode which can be observed from the peaks in the waveforms. Using the cable length and the time between the second and third peaks (12.6 μs), the propagation velocity is calculated, considering the length of the minor section (1080 m), as $2 \times 1080/12.6 = 171$ m/μs, which is close to the coaxial mode