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Real time prelocalization of underground single-phase cable insulation failure by using the sheath behavior at fault point

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ABSTRACT

This article presents a prelocalization approach of insulation faults affecting single-phase cables by using electrical measurements of voltage and current available in one substation. This approach is based on the theory of distributed parameters for modeling the faults to the ground. The specificity of this approach is the introduction of a resistance modeling the sheath-ground insulation allowing us to study the various types of faults to the ground (frankly and resistive). The fault distance and resistances are determined by two methods numerical and analytical. Many fault scenarios applied to the 150 kV underground cable connecting HTB sub-stations of Tyna–Taparoura–Sidimansour in Sfax, show a good agreement between the two methods. A simulation of the global system using the software Simulink-SimPowerSystems of Matlab is carried out giving us the voltages and currents on the source side necessary to the execution of the developed methods and the validation of the obtained results.

1. Introduction

The transport of the electric power since the production centers is ensured by overhead lines and underground cables. These latter undergo a fast evolution imposed by the increase in the urban zones and by a better quality of service and environment required by electricity consumers. Moreover, the recent technological developments have supported the choice of the underground cables by the adoption of new materials (synthetic insulator, aluminum sheath, ...) and new installation methods that reduce the capital costs [1].

Compared to the overhead lines, the underground cables present many advantages. It is very important to note that they do not need maintenance and especially are not affected by the unfavorable climatic conditions. But, when an incident happens, the restore time is relatively long due to the various stages of fault identification, classification and location estimation in differed time [1,2]. Then, in order to guarantee the continuity of the electric power, the electricity companies request to identify and locate with precision and rapidity the faulty segment in order to reduce the interruption duration [3]. This objective can be reached only by the implementation of simple, fast and accurate techniques of fault prelocalization.

The aim of this article is to develop two methods, analytical [4] and numerical, to prelocate ground faults affecting the single-phase underground cables. This study is made in collaboration with the Tunisian Company of Electricity and Gas (STEG) on the occasion of the new project of underground cable connecting HTB substations of Tyna, Taparoura and Sidimansour in Sfax.

In this work, we are interested in a configuration of an underground shielded HTB single-phase cable. The cable modeling is based on the distributed parameters theory [4–7]. The development of the fault equations requires the knowledge of the boundary conditions which are given from the recordings of voltage and current available at substation source and the network configuration.

The originality of the proposed approach resides in taking into account both fault resistances (core-sheath and sheath-ground). It can be thus applied to the various types of fault to the ground (frank and resistive). Fault distance and resistance values are determined by combining the system behavior before and during the incident. Several real-case simulations using the software Simulink-SimPowerSystems of Matlab are presented and compared with the two developed methods. The obtained results are in good agreement and prove the reliability of the presented approach.

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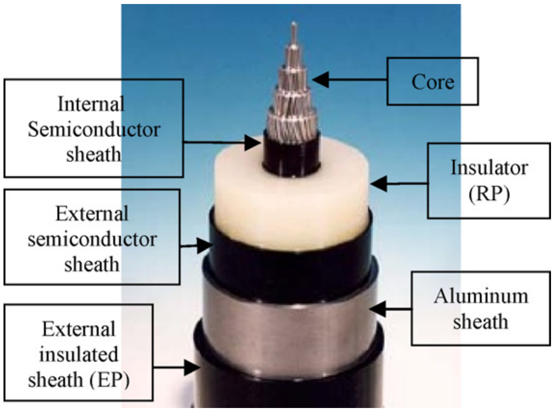

Fig. 1. Exploded design of a HTB shielded cable.

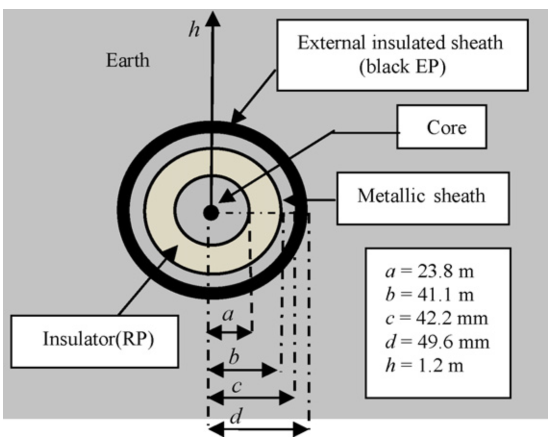

Fig. 2. Cross-section and geometrical data of the cable.

2. Cable description and modeling

The selected cable is a shielded single core underground 150 kV type. Figs. 1 and 2 present respectively the exploded and sectional views of the cable.

2.1. Cable description

An insulated cable is considered as a coaxial system made up of a copper or aluminum central conductor (core) in which the phase current circulates. This conductor is surrounded by an insulating envelope (RP: reticulated polyethylene). An outside metallic sheath plays at the same time the role of a reference electrode, an evacuating path of the short-circuit current, a sealing barrier and, eventually, a mechanical protection [1]. This sheath is covered generally with an external synthetic material extruded polyethylene (black EP) [8–10].

The AC current transit creates a magnetic field outside inducing overvoltage within the whole of the close conductors, which are affected by this magnetic field and particularly the metal sheath. In order to reduce overvoltage, we need to connect the sheath to ground at least in one point [1,11]. The earth connection system of the sheath is necessary to ensure:

- the limitation of the induced voltages in the sheath;
- the reduction of the losses in the sheath;
- the continuity of a return path for the fault currents and an adequate protection against the electric arcs and the failing loads.

In the case of our model, the earth connection system is the solid-bonding where the sheath is put in the ground at the two ends through identical resistances R_n.

2.2. Cable modeling

An elementary cable section is represented by three distributed model conductors presenting core, sheath and ground (Fig. 3) [9,12,13]. Each conductor is modeled longitudinally by an impedance per unit length $Z = R + jL\omega$ and transversely by an admittance per unit length $Y = G + jC\omega$. R and L represent respectively the resistance and the inductance of the conductor whereas ω (rd/s) indicates the alternative pulsation. It is of interest to indicate that both the conductance G and the capacitance C depend on the insulators nature between core and sheath (RP) and between ground and sheath (EP).

Voltage $v(x,t)$ and current $i(x,t)$ are functions of time t and distance x counted positively from the emission to the reception. By applying the Kirchhoff laws to the suggested elementary model, the expressions of the voltage drop and the current flows in the core and the sheath are given by (1) and (2) [12,13].

$$\frac{\partial v_{kg}}{\partial x} = R_k i_k + L_k \frac{\partial i_k}{\partial t} + \sum_{\substack{j=c,s,g\\ j\neq k}} M_{kj} \frac{\partial i_j}{\partial t} - R_g i_g - L_g \frac{\partial i_g}{\partial t} - \sum_{j=c,s} M_{jg} \frac{\partial i_j}{\partial t} \qquad (1)$$

$$\frac{\partial i_k}{\partial x} = \sum_{\substack{j=c,s,g\\ j\neq k}} G_{kj} v_{kj} + \sum_{\substack{j=c,s,g\\ j\neq k}} C_{kj} \frac{\partial v_{kj}}{\partial t} \qquad (2)$$

M_{kj} is the mutual inductance between conductors k and j. Indices c, s and g refer to core, sheath and ground conductors whereas k concern core and sheath one.

The per unit parameters (R, L, M, C and G) are given by taking into account the physical and geometrical characteristics of the cable [4,12,13].

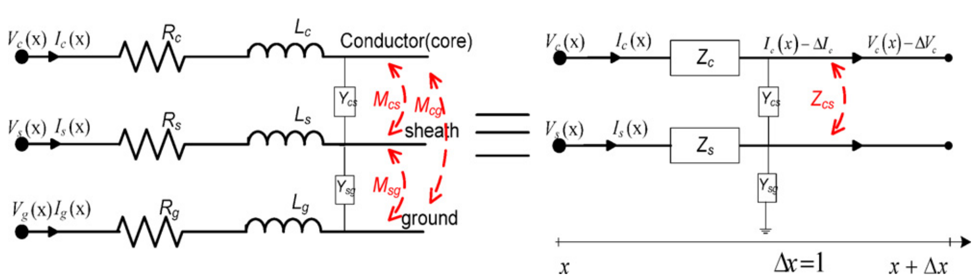

Fig. 3. Distributed parameters cable model.