Real time Prelocalisation of Electrical Defaults on High Voltage Underground Cable (single-phase case)

THAMEUR ALOUI, FATHI BEN AMAR, NIZAR DERBEL, HSAN HADJ ABDALLAH
National school of Engineering, BP W, 3038, Sfax
TUNISIA
taloui@steg.com.tn , Fathi.Benamar@ipeis.rnu.tn,

Abstract: - This paper proposes an assistance tool to the prelocalisation of the insulation defaults affecting electrical single-phase cables by using voltage and current measurements available in source substation. An equivalent network modeling defaults to the ground is analyzed by employing the distributed parameters approach. The per unit length values of these parameters are calculated according to the geometrical data of the cable. The specificity of this tool is the introduction of a resistance modeling sheath-ground insulation for the study of the various types of defaults to the ground (frank and resistive). Scenarios of default fault are applied to the underground cable 150 kV, connecting sub-stations HTB of Tyna – Taparoura - Sidimansour in Sfax. A validation study is approved by the software Simulink-SimPowerSystems of Matlab.

Key-Words: - Underground cable, Sheath, Insulation default, Prelocalisation, Default distance, Distributed parameters.

1 Introduction

We can't deny the importance of the electric power in our everyday life in addition to its contribution in the world industrial improvement.

The transport of energy since the electrical production centers is ensured by the overhead lines and the underground cables. The distribution's underground networks and especially of transmission systems know a fast evolution imposed by the urban zones development and a better quality of service and environment required by us. The choice of the buried cables is related to the recent technological progress by the adoption of new materials (synthetic insulator, aluminum sheath...) and new installation methods and consequently the reduction in the capital costs.

The underground cables of electricity have many advantages compared to the overhead lines. Indeed, they practically do not require maintenance and especially are not affected by the unfavorable climatic conditions. However, at fault, the restore time is relatively long due to the various stages of fault identification, classification and location estimation in differed time [1].

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 [2]. This target can be reached only by the implementation of simple, fast and accurate techniques of default prelocalisation. The paper aims is to develop a decision assistance tool of prelocalisation of the ground defects affecting the single-phase underground cables. Benefiting from the opening of the university on the industrial environment, 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. The per unit length parameters are given according to the physical laws [3].

The development of the defect equations requires the knowledge of the boundary conditions. These last are given from the recordings of voltage and current available at substation source and the network configuration.

The characteristic of the proposed algorithm is the taking into account of both default resistances core-sheath and sheath-ground. It can be thus applied to the various types of default to the ground (frank and resistive). The distance and the two resistances of the default are given by combining the system behavior before and during the incident. Several real-case simulations using the developed tool are presented and compared with the obtained results with the software SimPowerSystems of Matlab.

2 Determination of cable parameters and modeling

The selected cable is a shielded unipolar underground 150 kV type. Figures 1 and 2 respectively present the exploded and sectional views.

2.1 General description of cable

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 (PR: 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) [4].

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, connecting the sheath to ground, at least in one point, is needed [1].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 default currents and an adequate protection against the electric arcs and the failing loads.

In the case of our model, the sheath is put in the ground at the two ends through identical resistances R_n.

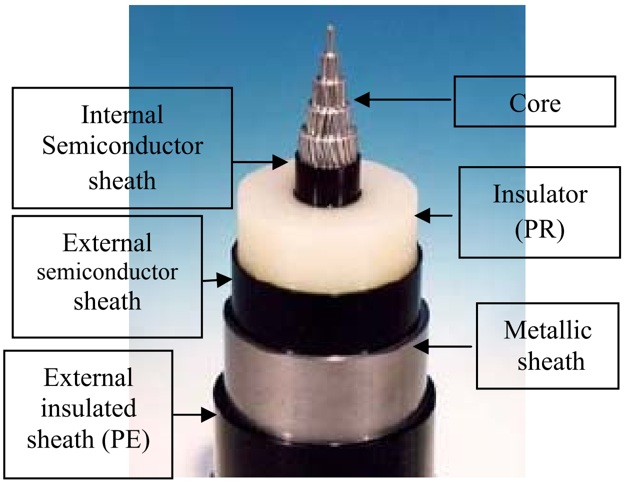

Fig.1: Explode design of a HTB shielded cable.

2.2 Cable modeling

An elementary cable section is represented by three conductors distributed model presenting core, sheath and ground (figure 3) [3]. Each conductor is modeled longitudinally by impedance per unit length $Z = R + jL\omega$ and transversely by admittance per unit length $Y = G + jC\omega$. It is interest to notify that the conductance G and the capacitance C depend on the insulators nature between core and sheath (PR) on the one hand and between ground and sheath (PVC) on the other hand.

Voltage $v(x,t)$ and current $i(x,t)$ are functions of time t and distance x counted positively from the emission to the receiver. 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 written by (1) and (2) [3].

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

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

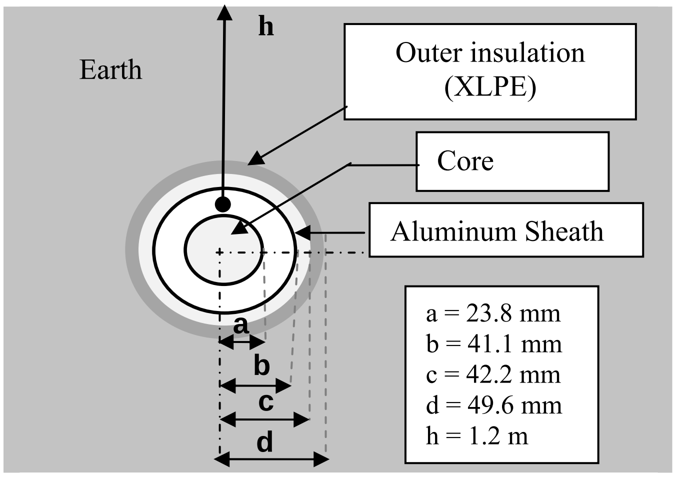

Fig.2: Sectional and geometrical data of the cable.

2.3 Per unit values parameters calculation

The physical parameters (R, L, C and G) are given analytically by taking account of the physical and geometrical characteristics of the cable. Resistance is calculated depending on the material resistivity, inductance is related to the magnetic field whereas the capacitance is given from the electric field. The conductance is expressed by the energy dissipation in the insulator [3].

2.3.1 Resistances per unit length

Cable resistances traduce the joule effect losses in the conductors. They are, indeed, equal to those measured in D.C. current when the current density is uniform. In alternative variable mode, the current density becomes not uniform; it is greater in surface than inside due to the skin effect (figure 4) which limits the penetration δ (3) of the alternating field in material.

$$\delta = \sqrt{\frac{2\rho}{\mu_0 \mu_r \omega}} \quad (3)$$

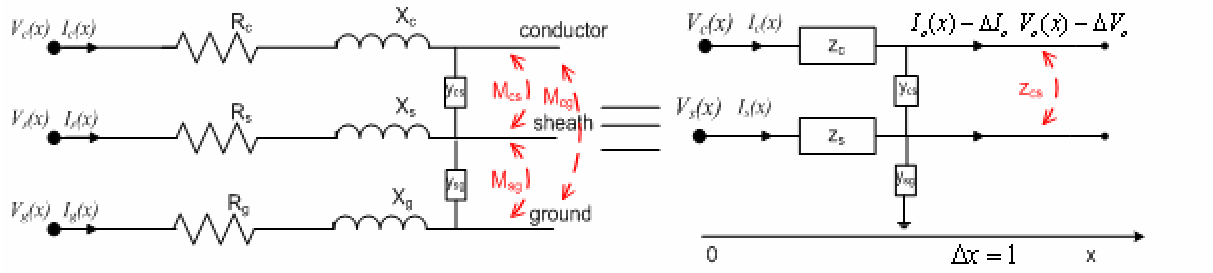

Fig.3: Distributed parameters cable model.

In this case, the core resistance is given by relation (4):

$$R_c = \frac{\rho}{\pi\left[a^2 - \left(a - \sqrt{\dfrac{2\rho}{\mu_0 \mu_r \omega}}\right)^2\right]} \qquad (4)$$

The ground is modeled by a cylinder of ray equal to its penetration thickness [3]. The sheath and ground resistances are then given respectively by the expressions (5) and (6).

$$R_s = \rho_s \frac{1}{\pi\left(c^2 - b^2\right)} \qquad (5)$$

$$R_g = \rho_g \frac{1}{\pi \delta_g^2} \qquad (6)$$

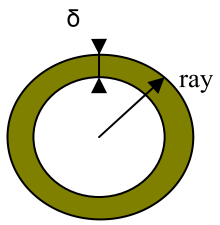

Fig. 4: Skin effect.

2.3.2 Inductances per unit length

The cable inductances are the most significant physical parameters. Indeed, its reactances are dominant in the cable impedances expressions. The determination of these inductances is based on the quantities of stored magnetic energy calculated by the Lagrangian expression [3]. Self and mutual inductances relating to the model suggested are then given by equations system (7).

2.3.3 Capacitances per unit length

The cable capacitances are due to the potential differences which exist between the three conductors. We define then a capacitance C_{cs} between the core and the sheath and another one C_{sg} between the sheath and the ground. These two capacitances are calculated from the Gauss theorem [3] and given by (8).

$$\begin{aligned}
L_C &= -\frac{\mu_0}{2\pi}\ln\frac{a}{1} + \frac{\mu_0}{8\pi} \\
L_s &= -\frac{\mu_0}{2\pi}\left[\frac{c^2(c^2-2b^2)}{(c^2-b^2)^2}\ln\frac{c}{1} + \frac{b^4}{(c^2-b^2)^2}\ln\frac{b}{1} + \frac{b^2}{2(c^2-b^2)}\right] + \frac{\mu_0}{8\pi} \\
L_g &= -\frac{\mu_0}{2\pi}\ln\frac{\delta_g}{1} + \frac{\mu_0}{8\pi} \\
M_{cs} &= -\frac{\mu_0}{2\pi}\left[\frac{c^2}{(c^2-b^2)}\ln\frac{c}{1} - \frac{b^2}{(c^2-b^2)}\ln\frac{b}{1} - \frac{1}{2}\right] \\
M_{cg} &= M_{sg} = -\frac{\mu_0}{2\pi}\left[\ln\frac{\delta_g}{1} - \frac{h}{\delta_g}\left(1 - \frac{h}{2\delta_g}\right)\right]
\end{aligned} \qquad (7)$$

$$\begin{aligned}
C_{cs} &= \frac{2\pi\,\varepsilon_0\,\varepsilon_{rcs}}{\ln\dfrac{b}{a}} \\
C_{sg} &= \frac{2\pi\,\varepsilon_0\,\varepsilon_{rsg}}{\ln\dfrac{d}{c}}
\end{aligned} \qquad (8)$$

2.3.4 Conductances per unit length

The cable conductances correspond to the transverse losses due to the imperfect nature of dielectric between the conductors core-sheath and ground-sheath. Generally, these conductances are negligible [3].

2.4 Model equations

In permanent sinusoidal mode, the relations (1) and (2) of the model are written in the matrix form, as (9):

$$\begin{bmatrix} \dfrac{\partial V}{\partial x} \\ \dfrac{\partial I}{\partial x} \end{bmatrix} = \begin{bmatrix} 0 & Z \\ Y & 0 \end{bmatrix} \times \begin{bmatrix} V \\ I \end{bmatrix} \qquad (9)$$

ISSN: 1790-5117

ISBN: 978-960-474-185-4

where V and I represent respectively the vectors column voltage and current relating to the core and the sheath:

$$V = [\,V_c \quad V_s\,]^T \quad ; \quad I = [\,I_c \quad I_s\,]^T \tag{10}$$

The impedance Z and admittance Y matrices are square of order 2 and symmetrical as (11).

$$Z = \begin{bmatrix} z_c & z_{cs} \\ z_{cs} & z_s \end{bmatrix} ; \; Y = \begin{bmatrix} y_{cs} & -y_{cs} \\ -y_{cs} & y_{cs} + y_s \end{bmatrix} \tag{11}$$

with:

$$\begin{aligned} z_c &= R_c + R_g + j\omega(L_c + L_g - 2M_{cg}) \\ z_{cs} &= R_g + j\omega(L_g + M_{cs} - 2M_{cg}) \\ z_s &= R_s + R_g + j\omega(L_s + L_g - 2M_{sg}) \end{aligned} \tag{12}$$

To separate the voltage and current variables from the matrix equation (14), we calculated the second order differential equation $\frac{\partial^2 V}{\partial x^2}$ and $\frac{\partial^2 I}{\partial x^2}$; what gives a solution as (13) :

$$\begin{aligned} V(x) = {} & K_1 \exp(\lambda_1 x) + K_1^{'} \exp(-\lambda_1 x) + \\ & K_2 \exp(\lambda_2 x) + K_2^{'} \exp(-\lambda_2 x) \end{aligned} \tag{13}$$

where K_1, $K_1^{'}$, K_2 and $K_2^{'}$ are vectors constants depending on the boundary conditions. The eigenvalues λ_1 and λ_2 are given from the characteristic equation: $\det(\lambda I - ZY) = 0$

The solution (13) can be expressed by hyperbolic functions as (14) [2, 5].

$$\begin{aligned} V_c(x) = {} & C_1 \cosh(\lambda_1 x) + C_2 \sinh(\lambda_1 x) + \\ & C_3 \cosh(\lambda_2 x) + C_4 \sinh(\lambda_2 x) \\ V_s(x) = {} & C_1^s \cosh(\lambda_1 x) + C_2^s \sinh(\lambda_1 x) + \\ & C_3^s \cosh(\lambda_2 x) + C_4^s \sinh(\lambda_2 x) \end{aligned} \tag{14}$$

The coefficients C_i and C_i^s for $i = [1-4]$ depend on voltages and currents available in source substation at the incident time and the various boundary conditions. Then:

$$\begin{aligned} \frac{\partial V_c(x)}{\partial x} = {} & \lambda_1 C_1 \sinh(\lambda_1 x) + \lambda_1 C_2 \cosh(\lambda_1 x) + \\ & \lambda_2 C_3 \sinh(\lambda_2 x) + \lambda_2 C_4 \cosh(\lambda_2 x) \\ \frac{\partial V_s(x)}{\partial x} = {} & \lambda_1 C_1^s \sinh(\lambda_1 x) + \lambda_1 C_2^s \cosh(\lambda_1 x) + \\ & \lambda_2 C_3^s \sinh(\lambda_2 x) + \lambda_2 C_4^s \cosh(\lambda_2 x) \end{aligned} \tag{15}$$

From relations (14-16) and while posing $a = z_c z_s - z_{cs}^2$, we obtain:

$$\begin{aligned} aI_c(x) &= z_s \frac{\partial V_c(x)}{\partial x} - z_{cs} \frac{\partial V_s(x)}{\partial x} \\ aI_s(x) &= z_c \frac{\partial V_s(x)}{\partial x} - z_{cs} \frac{\partial V_c(x)}{\partial x} \end{aligned} \tag{16}$$

Then, equations (20) and (21) give:

$$\begin{aligned} I_c(x) = {} & \frac{\lambda_1}{a}[(z_s C_1 - z_{cs} C_1^s) \sinh(\lambda_1 x) + \\ & (z_s C_2 - z_{cs} C_2^s) \cosh(\lambda_1 x)] + \\ & \frac{\lambda_2}{a}[(z_s C_2 - z_{cs} C_3^s) \sinh(\lambda_2 x) + \\ & (z_s C_4 - z_{cs} C_4^s) \cosh(\lambda_2 x)] \\ I_s(x) = {} & \frac{\lambda_1}{a}[(z_c C_1^s - z_{cs} C_1) \sinh(\lambda_1 x) + \\ & (z_c C_2^s - z_{cs} C_2) \cosh(\lambda_1 x)] + \\ & \frac{\lambda_2}{a}[(z_c C_3^s - z_{cs} C_3) \sinh(\lambda_2 x) + \\ & (z_c C_4^s - z_{cs} C_4) \cosh(\lambda_2 x)] \end{aligned} \tag{17}$$

Next:

$$\begin{aligned} \frac{\partial I_c(x)}{\partial x} = {} & \frac{\lambda_1^2}{a}[(z_s C_1 - z_{cs} C_1^s) \cosh(\lambda_1 x) + \\ & (z_s C_2 - z_{cs} C_2^s) \sinh(\lambda_1 x)] + \\ & \frac{\lambda_2^2}{a}[(z_s C_2 - z_{cs} C_3^s) \cosh(\lambda_2 x) + \\ & (z_s C_4 - z_{cs} C_4^s) \sinh(\lambda_2 x)] \\ \frac{\partial I_s(x)}{\partial x} = {} & \frac{\lambda_1^2}{a}[(z_c C_1^s - z_{cs} C_1) \cosh(\lambda_1 x) + \\ & (z_c C_2^s - z_{cs} C_2) \sinh(\lambda_1 x)] + \\ & \frac{\lambda_2^2}{a}[(z_c C_3^s - z_{cs} C_3) \cosh(\lambda_2 x) + \\ & (z_c C_4^s - z_{cs} C_4) \sinh(\lambda_2 x)] \end{aligned} \tag{18}$$

In the same way, after manipulating relations (9), (11) and (14), we obtain in (19) new expressions of currents differential form $I_c(x)$ and $I_s(x)$.

While equalizing (18) and (19), we deduce the final equations system in (20) characterizing the cable model

$$
\begin{aligned}
\frac{\partial I_c(x)}{\partial x} &= (y_c C_1 + y_{cs} C_1^s)\cosh(\lambda_1 x) + \\
&(y_c C_2 - y_{cs} C_2^s)\sinh(\lambda_1 x) + \\
&(y_c C_2 + y_{cs} C_3^s)\cosh(\lambda_2 x) + \\
&(y_c C_4 + y_{cs} C_4^s)\sinh(\lambda_2 x) \\
\frac{\partial I_s(x)}{\partial x} &= (y_s C_1^s + y_{cs} C_1)\cosh(\lambda_1 x) + \\
&(y_s C_2^s + y_{cs} C_2)\sinh(\lambda_1 x) + \\
&(y_s C_3^s + y_{cs} C_3)\cosh(\lambda_2 x) + \\
&(y_s C_4^s + y_{cs} C_4)\sinh(\lambda_2 x)
\end{aligned} \tag{19}
$$

$$
\begin{aligned}
V_c(x) &= C_1\cosh(\lambda_1 x) + C_2\sinh(\lambda_1 x) + \\
&C_3\cosh(\lambda_2 x) + C_4\sinh(\lambda_2 x) \\
V_s(x) &= C_1\alpha_1\cosh(\lambda_1 x) + C_2\alpha_1\sinh(\lambda_1 x) + \\
&C_3\alpha_2\cosh(\lambda_2 x) + C_4\alpha_2\sinh(\lambda_2 x) \\
I_c(x) &= C_1\alpha_3\sinh(\lambda_1 x) + C_2\alpha_3\cosh(\lambda_1 x) + \\
&C_3\alpha_4\sinh(\lambda_2 x) + C_4\alpha_4\cosh(\lambda_2 x) \\
I_s(x) &= C_1\alpha_5\sinh(\lambda_1 x) + C_2\alpha_5\cosh(\lambda_1 x) + \\
&C_3\alpha_6\sinh(\lambda_2 x) + C_4\alpha_6\cosh(\lambda_2 x)
\end{aligned} \tag{20}
$$

with α_i (i=1 à 6) are constants expressed by the relations system (21).

$$
\begin{aligned}
\alpha_1 &= \frac{z_s\lambda_1^2 - \left(z_c z_s - z_{cs}^2\right)y_c}{z_{cs}\lambda_1^2 + \left(z_c z_s - z_{cs}^2\right)y_{cs}} \\
\alpha_2 &= \frac{z_s\lambda_2^2 - \left(z_c z_s - z_{cs}^2\right)y_c}{z_{cs}\lambda_2^2 + \left(z_c z_s - z_{cs}^2\right)y_{cs}} \\
\alpha_3 &= \frac{-\lambda_1\left(z_s - z_{cs}\alpha_1\right)}{\left(z_c z_s - z_{cs}^2\right)} \\
\alpha_4 &= \frac{-\lambda_2\left(z_s - z_{cs}\alpha_2\right)}{\left(z_c z_s - z_{cs}^2\right)} \\
\alpha_5 &= \frac{-\lambda_1\left(z_c\alpha_1 - z_{cs}\right)}{\left(z_c z_s - z_{cs}^2\right)} \\
\alpha_6 &= \frac{-\lambda_2\left(z_c\alpha_2 - z_{cs}\right)}{\left(z_c z_s - z_{cs}^2\right)}
\end{aligned} \tag{21}
$$

4 Prelocalisation of a single-phase default "core-sheath-ground"

We assume a short circuit with the ground according to the configuration of figure 5.

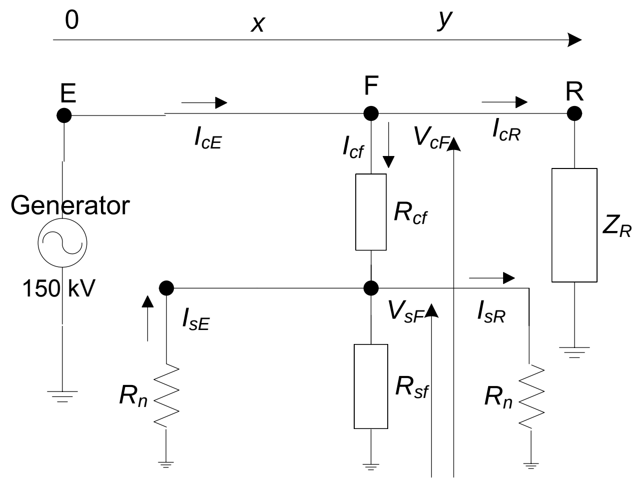

Fig.5 : Default network

The default impedances core-sheath and sheath-ground are supposed to be resistive R_{cf} and R_{sf} respectively. For the determination of the boundary conditions, we decomposed the network, at the default point (F), into upstream and downstream circuits. The upstream circuit extends from the emission E (voltage source) to the default point. The downstream circuit extends from the default point to the reception R (load).
These two circuits obey the equations system (20) with the following boundary conditions (22, 23):

- Upstream circuit : $0 \le x \le d$

$$
\begin{aligned}
&V_{cE}(0) = V_c^m \\
&I_{cE}(0) = I_c^m \\
&V_{sE}(0) = -R_n I_{sE}(0) \\
&I_{sE}(0) = I_s^m
\end{aligned} \tag{22}
$$

- Downstream circuit: $0 \le y \le (l-d)$

$$
\begin{aligned}
&V_{cF} = V_{cE}(d) \\
&V_{cF} = V_{cR}(0) \\
&V_{sF} = V_{sE}(d) \\
&V_{sF} = V_{sR}(0) \\
&V_{cR}(l-d) = Z_R I_{cR}(l-d) \\
&V_{sR}(l-d) = R_n I_{sR}(l-d)
\end{aligned} \tag{23}
$$

The unknown factors C_1, C_2, C_3 and $C4$ are thus determined by combining the equations (20) and (22) for the upstream circuit and the equations (20) and (23) for the downstream circuit.
It should be noted that the load impedance Z_R is given with the healthy state just before the incident and we suppose that it remains unchanged during the default.
The default behavior at the point F is described by equation (24).

$$f(d,R_{sf}) = V_{sE}(d) - R_{sf}\left(I_{cE}(d) - I_{cR}(0) \right) + R_{sf}\left(I_{sE}(d) - I_{sR}(0) \right) = 0 \quad (24)$$

The two unknown factors d and R_{sf} are thus calculated from the real and imaginary parts of (24) by using the Newton Raphson iterative method.

To have an idea on the default resistance core-sheath value R_{cf}, the following relation (25) is used:

$$R_{cf} = \frac{V_{cE}(d) - V_{sE}(d)}{I_{cE}(d) - I_{cR}(0)} \quad (25)$$

The boundary conditions measured at source ($V_c(0)$, $I_c(0)$ and $I_s(0)$) necessary for the suggested algorithm execution are taken from the default simulation studied in the environment Simulmink-SimpowerSystems of Matlab. The fundamental module and argument of the measured values are extracted using the Fourier fast transform (TFF) [6].

For different values taken of R_{cf} and R_{sf} we simulated defects frank and resistive with Simulink at a distance x=100m of a cable portion length l=700m. The selected load impedance is equal to $Z_R = 648 + j314\,\Omega$ [5]. The obtained results are given in the tables (1-3). The obtained various voltage and current relating to the core and the sheath, resistances and distance of the default are compared.

The error of the estimated distance is calculated by (26).

$$\varepsilon = \frac{d - d_e}{l} \quad (26)$$

		$I_{cE}(d)$	$I_{cR}(0)$	$I_{sE}(d)$	$I_{sR}(0)$	V_{cF}	V_{sF}	$R_{cf}(\Omega)$	$R_{sf}(\Omega)$	d(m)	ε(%)
Simulink-Simpower	Mod (A, kV)	1.19E6	162	2.46E4	793.6	118.8	2.388	10^{-6}	10^{-6}	100	0.28
	Arg	-32.42°	-56.38°	-126.9°	-134.2°	-32.42°	-126.6°				
Outil proposé	Mod (A, kV)	1.19E6	162.7	2.47E4	671	118.87	2.028	0.09	6E-5	96.7	
	Arg	-32.42°	-56.32°	-126.9°	-133°	-33.39°	-124.8°				

Table 1: Frank default case (R_{cf}=0 Ω et R_{sf}=0 Ω).

		$I_{cE}(d)$	$I_{cR}(0)$	$I_{sE}(d)$	$I_{sR}(0)$	V_{cF}	V_{sF}	$R_{cf}(\Omega)$	$R_{sf}(\Omega)$	d(m)	ε(%)
Simulink-Simpower	Mod (A, kV)	3182	205.1	65.8	32.25	150	3.67	50	10^{-6}	100	0.25
	Arg	-1.58°	-24.07°	-96.45°	-117°	-0.082°	-77.53°				
Outil proposé	Mod (A, kV)	3182	205.1	67.2	29.9	149.97	1.09	39.6	3.6E-4	98.22	
	Arg	-1.58°	-24.07°	-95.77°	-132°	-0.083°	-0.95°				

Table 2: Resistive default case (R_{cf}=50 Ω et R_{sf}=0 Ω).

		$I_{cE}(d)$	$I_{cR}(0)$	$I_{sE}(d)$	$I_{sR}(0)$	V_{cF}	V_{sF}	$R_{cf}(\Omega)$	$R_{sf}(\Omega)$	d(m)	ε(%)
Simulink-Simpower	Mod (A, kV)	13.42E3	204.9	5.105E3	4.908E3	149.9	15.3	15	5	100	1.1
	Arg	-0.79°	-25.13°	-176.4°	-5.84°	-0.22°	-1.6°				
Outil proposé	Mod (A, kV)	13.42E3	205	5.104E3	4.908E3	149.9	15.3	10.17	4.69	108.33	
	Arg	-0.79°	-25.17°	-176.4°	-5.86°	-0.22°	-1.44°				

Table 3: Resistive default case (R_{cf}=15 Ω et R_{sf}=5 Ω).

We note that the voltage and current values obtained by the suggested assistance tool and the software simulink-SimPower are agreed perfectly along the cable and particularly at the default point F. However, the error estimated on the default distance varies according to the default place on the one hand and the default nature represented by resistances R_{cf} and R_{sf} on the other hand. Indeed, the error becomes significant for the resistive defaults because of the transverse capacitive currents effect which reduce the current crossing the default resistances [7].

Thus shown, the proposed tool can be applied to all types of defaults to the ground (frank or resistive) by taking account of the resistance of default sheath-ground R_{sf}.

To analyze the algorithm robustness to the variation of the fault position, we examined the estimated distance error for three incident cases.

Figure 6 illustrates the obtained results and shows that the maximum error reached is lower than 3%.

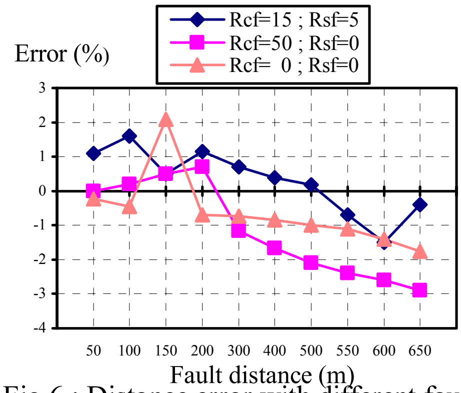

Fig.6 : Distance error with different fault positions.

4 Conclusion

The assistance tool developed in this study prelocates in real time and with precision the default position to the ground affecting the underground single-phase cables.

The step used is based on the distributed parameters approach to model the system cable-ground and the exploitation of the electrical recordings at source substation before and during the event. The metric values of these parameters are calculated by taking account of the physical and geometrical characteristics of the cable.

The prelocalisation tool characteristic is the taking into account of two resistances of default conductor-sheath and sheath -ground making it possible to study different types of default to the ground (frank and resistive).

Several scenarios of default simulation are carried out on an underground cable 150 kV connecting HTB sub-stations of Tyna, Taparoura and Sidimansour in Sfax.

The obtained results are validating with the Simulink-SimPowerSystems software showing the robustness of the developed tool according to the nature of the insulation default and the variation of its place. The error estimated on the default distance does not exceed 3%.

This work relates to the prelocalisation of the defaults to the ground affecting the single-phase cables. An extension for the three-phase cases is in hand.

References:

[1]Demetries A .Tziouraras , Protection of high – voltage AC cables, *IEEE xplore , Schewtzer engingaring laboratories*.

[2]El Sayed Tag El Din and Lee , Fault Location Scheme for Combined Overhead Line with Underground Power Cable, *Electric Power Systems Research*,Vol.76, 2006, pp. 988-935.

[3]Escané, *Réseaux d'Energie Electrique, Modélisation: llignes, câbles*, Eyrolles, 1997

[4]*IEEE Guide for Selection and Design of Aluminum Sheaths for Power Cables*, the Institute of Electrical and Electronics Engineers, 2004.

[5]Chee-Wooi Ten and lee, Fault Location for Underground Power Cable Using Distributed Parameter Approach, *IEEE Transaction on Power Systems*, Vol.23, No.4 2008, pp.1809-1816.

[6]Chul-Hwan Kim and Lee, Educational Use of EMTP Models for the Study of a Distance Relaying Algorithm for Protecting Transmission Lines, *IEEE Transactions on Power Systems*, Vol.15, No.1, 2000, pp.9-15.

[7]André D. Filomena, Fault Location for Underground Distribution Feeders: an Extended Impedance-based Formulation with Capacitive Current Compensation, *Electrical Power and Energy Systems*, Vol.31, No.9 2009, pp.489-496.

Nomenclature:

symbol	Designation	unity
R	Metric resistance	Ω/m
L	Metric inductance	H/m
C	Metric capacity	F/m
G	Metric conductance	s/m
M	Metric mutually inductance	H/m
S	conductor section	m^2
ρ	Electrical resistivity of the conductor	Ω.m
$\mu_0=4\pi 10^{-7}$	Permeability in the air	N/m
μ_r	Relative magnetic permeability of the conductor	
ω	Alternative pulsation	rd/s
$\varepsilon_0 = 10^{-9}/36\pi$	Vacuum permittivity	F/m
ε_r	relative permittivity	
I	identity Matrix	
j et k	concern the conductor and sheath	
c, s et g	concern the conductor, sheath and ground	