

Parametric Characterization of a Fault in a Shielded Cable Network

B. Nekhou¹ and S. Kaouche¹

¹Department of Electrical Engineering, University of Jijel – Algeria, nek_cem @univ-jijel.dz

Reliability of telecommunications and energy transport systems is principally based on the electrical state of cables and lines. Reflectometry, the basis of which is the analysis of an echo, is the most used in this case to characterize the link status which can be affected by various aggressions. In this paper, we propose a complete modeling which takes into account the propagation of a wave in a network of cables and the mathematical analysis of signals that may inform us about his condition. Our objective is to explain the origin of transient signals that may appear abnormally after mathematical analysis of the network response to an excitation. For the diagnosis of faults we use a parametric mathematical method, called windowed Pencil matrix, which allows a time-frequency analysis of the signals. This parametric representation allows us to determine the parameters describing a signal, a system or a process.

Index Terms — Diagnosis, faults, shielded cable, modeling, windowed matrix Pencil

I. INTRODUCTION

Reflectometry is a commonly used method for determining the electrical state of cables and lines. This method provides information for the detection, localization and characterization of electrical faults. Reflectometry is a diagnostic method based on the principle of radar. A probe signal is sent in the system or the environment to diagnose, this signal is propagated following the propagation laws of the studied medium and when it encounters a discontinuity (impedance), a part of its energy is returned to the injection point. The analysis of the reflected signal allows us to deduce information about the system or the considered medium.

In addition to telecommunications systems by conventional cables, in thirty years, the length of cables embedded on an automobile has more than tenfold, from about 200 to over 4000 meters. At the same time, the number of connections has increased two hundred to more than two miles: we understand that the interconnection network is now considered by manufacturers as a weak link for modern vehicles. Moreover, the arrival of technology "by wire" – That is to say replacement of major mechanical and hydraulic components by electronic systems programmed (steering, braking, suspension, etc.) – and all electric will give it a cardinal importance, because it will be the unique link between the driver, his actions, and the vehicle. The reliability of the wiring will become preponderant. This problem is also present in aviation, where cable lengths exceed several hundred kilometers in modern aircraft, domain where reliability is a vital issue. The analysis of defects on a cable or line is today a problem largely treated by reflectometry [1]. However, the phase of signal processing is essential for accurate analysis, and an accurate physical model is a plus for improve performance.

In this work we propose a complete modeling that deals with:

- the modeling of the propagation of a signal in a cable network to recover its echo;
- the mathematical processing of the echo recovered for fault diagnosis in the cable network.

Our work takes into account the nature of the cable (aerial or buried) and propose to deepen the analysis of a defect using mathematical processing of the signal. We search a description more effective of the signal characteristics that allow for

example reduce the performance space or to extract some information more easily. For this purpose, we use a spectral estimation method called "Matrix Pencil" better preferment on short samples.

II. PROPAGATION MODELING IN A NETWORK OF CABLES

In this work, we define by network, a set of shielded cables (propagating links) interconnected by junctions (interconnection node). A shielded cable is modeled as a Multiconductor Transmission Line (MTL) [2].

To model the propagation of a harmonic or transient electric wave in a network of shielded cables, we use the topological formalism which is mathematically defined as follows [2]:

$$[A] \times [X] = [B] \quad (1)$$

$[A]$: topological matrix which takes into account the configuration of the network cables.

$[X]$: Vector of unknowns (currents and voltages at all nodes);

$[B]$: Source vector (localized sources of current or voltage).

$$[A] = \begin{bmatrix} [A_1] \\ [A_2] \end{bmatrix} \quad (2)$$

$[A_1]$: submatrix deduced after representation of a cable by a quadrupole (in frequency or in time) which expresses the current-voltage relations between its two extremities [2].

$[A_2]$: submatrix deduced from Kirchhoff's laws (KCL and KVL) for junctions and end networks [2].

III. PARAMETRIC MODELING OF SIGNALS

Estimation of the spectral characteristics of discrete deterministic or stochastic signals is generally based on the use of the Fourier Transform (FT). This approach of the spectral analysis is interesting from the point of view of computability and gives satisfactory results for a broad class of signals; however, several drawbacks inherent in the method limit its performances:

- The inverse frequency resolution of the number of samples and the window effect that can manifest itself in the spectral domain by a significant loss of information (distortion and masking of the spectral patterns present);
- The use of appropriate window can reduce these disadvantages but at the cost of a loss of resolution. These limitations of FT are particularly penalizing when

analyzing transient signals.

The use of more efficient spectral estimation methods on short samples such as parametric methods represents an interesting alternative. Generally, parametric modeling techniques used to determine the parameters of a mathematical model describing a signal, system, or process, are [3]:

- Original Prony Method
- Matrix Pencil Method
- Short-Time Matrix Pencil Method

IV. APPLICATIONS

Detection of non-frank defects is a very important step in the inspection of the condition of underground cables to cope with the predominance of curative maintenance to the detriment of preventive maintenance. As an application, we propose to simulate a non-straightforward defect which is due to the penetration of water over a short length of the underground cable (see figure 1) whose data are in Table 1.

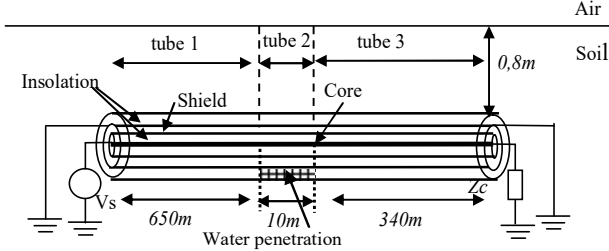


Fig. 1. Geometric configuration of the underground cable.

TABLE I
PHYSICAL AND GEOMETRIC DATA OF THE UNDERGROUND CABLE

	Core	Insulation	Shield	Sheath
Length(m)	1000	/	/	/
Diameter (mm)	17	25	25,6	32, 6
Materials	Alum.	PR	Copper	PR

The penetration of water (over a length of 10 m), will change the physical properties of the dielectric surrounding the shield. This section of insulation of the underground cable becomes conductive (water). To modelise this fault, the underground cable is divide in three tube (figure 1).

As a reference signal, we inject into the first end of the cable pulses provided by a Gaussian-type voltage generator, whose mathematical expression is as follows:

$$V_s(t) = e^{-\alpha(t-\beta \cdot dt)^2}, \quad \alpha = (4 / (\beta \cdot dt))^2, \quad \beta = 5$$

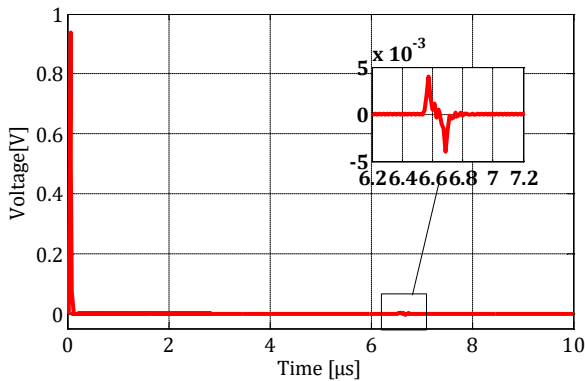


Fig. 2. Voltage signal at the input of the core of the underground cable with fault (penetration of water from 650m).

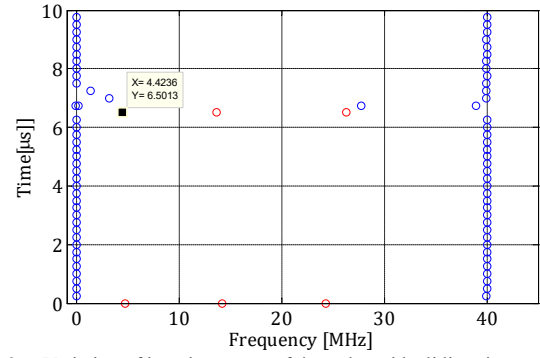


Fig. 3. Variation of imaginary part of the poles with sliding time.

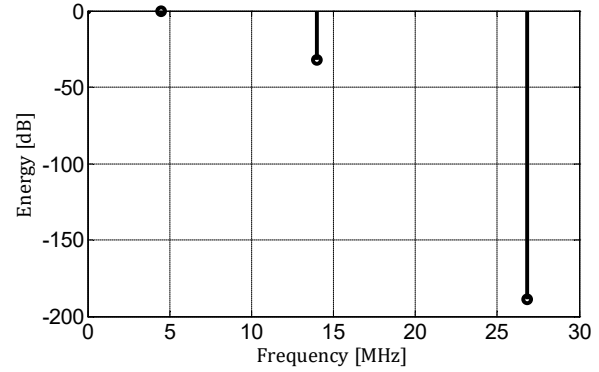


Fig. 4. Modal Energy.

TABLE 2
CHARACTERISTIC PARAMETERS OF THE ECHO

Frequency [MHz]	Damping coefficient	Residues [V]	Modal Energy [dB]
26.836937	-1.186440e+006	3.556086e-008	-1.886971e+002
14.006419	-1.133252e+006	8.668559e-001	-3.194121e+001
4.497315	-1.317898e+006	5.878341e+000	0

For the processing of the signal obtained in figure 2 by STMPM Method (figure 3) we have chosen the parameters: Sampling step $dt=1.25 \cdot 10^{-9}$ s, Number of windows 40 and Number of poles 6. The results put in case the presence of two events. The first corresponds to the pulse injected at the entrance of the cable and the second corresponds to the inhomogeneity introduced by the presence of the penetration of water on a part of the insulation (calculated distance $d = 651$ m). Table 2 gives the characteristic parameters of the echo. The dominant frequency is 4,497 MHz is accompanied by the highest residue and the highest energy (figure 4). All this information can easily help in diagnosing the hidden defect.

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