Characterization of Medium Voltage Cables for Power Line Communication

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***Abstract*— In this paper a new approach is proposed, for the detection of harmonic sources in polluted power systems. It is a single-point strategy, based on a comparison among different "nonactive" power quantities proposed in literature, that, in the same working conditions, assume different values at the metering section. Some simulations tests were carried out on a standard IEEE test system, proposed, by other authors, as a benchmark system for the analysis of multi-point measurement techniques for harmonic pollution monitoring. The obtained results show that the proposed single point approach is in agreement with other strategies already proposed in literature and can give useful indications for the detection of the dominant harmonic source in a metering section also in some critical cases.**

Index Terms— power quality, harmonic distortion, reactive power, power system harmonics, detection of harmonic sources.

I. Introduction

Power Line Communication (PLC) is a communication technology proposed as integration service system on electric power network for transmission of information (voice, images and data). The extension of electric power networks enables to reach out areas wider than those areas accessible by a typical telephonic network. This technology does not involve any installation cost or any special maintenance, because cables of existing power line are used. The operation rule of PLC systems is synthetically the following: a high frequency signal is injected in a power line with a coupling device.

In Europe, the available frequency intervals for communication systems on LV and MV power networks are settled by CENELEC EN 50065-1 [1]. The EN 50065-1 specifies five different bandwidths from 3 kHz to 148 kHz. The use of the frequencies in 3 kHz – 95 kHz range, is permitted only to the power utilities and its customers for data exchange, as the remote metering of power meters or for the control systems of electrical burdens. The use of the frequencies in 95 kHz – 148.5 kHz is permitted to the customers only.

In Northern America and in Japan the regulation is more permissive because allows to use frequencies up to 525 kHz, i.e. up to the AM broadcast threshold [2].

A further reference for PLC systems is the IEEE standard 643 – 2004 [3].

PLC has been object of the scientific research since early '70s of 20th century in HV power systems, in order to apply this technology to the management and control of HV transmission networks.

Nowadays, the most technical effort has been performed principally for LV power line channels, because of the huge development of PLC in home applications [4-5].

On the other hand, only recently the application of PLC to MV power networks has been taken into account. The most important applications for MV networks concern:

- monitoring systems (temperature measurement of oil transformers, voltage measurement on secondary winding of HV/MV transformers, fault survey, power quality measurement, and remote control for prevention of the islanding phenomenon) [6].
- operational services (remote control, emergency signals, security systems, emergency and maintenance telephony).
- network management optimization (possibility of minimizing the unexpected harmful events as faults, off-duty, network maintenance).

A further interesting application of PLC technology in MV networks is the possibility to diagnose on line and in real-time the presence of partial discharges into the cables and consequently to supervise continuously the dielectric degradation in order to plan maintenance [7].

With reference to the transmission channel type for cable lines, two configurations are mainly used, line-ground and line-line configuration. In the line-ground configuration the signal is injected between a phase and cable shield. The shield is normally connected to the ground at the ends of the line. In the line-line configuration, the signal is injected between two phases of a three-phase power system, or between the phase and the neutral conductor of a single-phase power system. In both cases the signal can be injected by capacitive couplers or inductive couplers.

Therefore, the characterization of the transmission channel at high frequencies is firstly required in order to perform a planning of a MV PLC transmission system,.

In scientific literature, there are different studies on the behaviour of MV overhead lines and on HV lines at high frequency. On the other hand, there are few studies on the behaviour of MV cable lines [8-9]. Even though the mathematical approach for the characterization of cables is the same for LV and MV lines, i.e. the transmission line theory, it is necessary to take into account the different constructive structure of the MV cables compared with the LV cables. The most important difference is the presence, in MV cables, of the shield and the semiconductor screen [7].

The aim of this paper is to characterise a MV cable in two different transmission line configurations:

- single cable with signal transmission injected between the core and the shield;
- two cables with signal transmission injected between their cores. In this case, the shields are connected to both ends.

In the paper firstly some theoretical remarks on the parameters of MV cables are developed. Secondly, the measurement set up is described. Finally, measurements results are presented in the case of two unipolar MV shielded cables type RG7H1R, one of 185 mm^2 cross-section with aluminum core and the other of 95 mm^2 cross-section with copper core. The rated voltage for both the cables is 30 kV.

II. Theoretical Model

In literature the methods used to simulate and to study the transmission line behavior are various and all originate from the time dependent telegrapher's equations. The elementary line transmission cell is shown in Fig. 1.

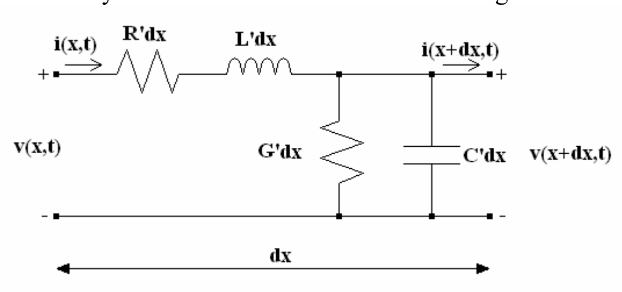


Fig. 1 – Elementary cell of a transmission line

The telegrapher's equations are the following:

$$\frac{\partial v(x,t)}{\partial x} + R' i(x,t) + L' \frac{\partial i(x,t)}{\partial t} = 0 \qquad (1)$$

$$\frac{\partial i(x,t)}{\partial x} + G' v(x,t) + C' \frac{\partial v(x,t)}{\partial t} = 0 \qquad (2)$$

In these equations *x* denotes the longitudinal direction of the line and R', L', G' and C' are the constant per unit length resistance, inductance, conductance and capacitance, respectively whereas *v* and *i* are the voltage and current line.

The physical interpretation of *f(x-ct)* is a wave travelling at velocity *c* in a forward direction and of *g(x-ct)* is a wave travelling at velocity *c* in a backward direction.

The most important parameters of a transmission line are the characteristic impedance Z_c [Ω] and the attenuation constant α [dB/km].

From the theory, it's well known that the characteristic impedance Z_c is calculated as follows:

$$Z_C = \sqrt{\frac{Z_{sh}}{Y_0}} \qquad (3)$$

where Z_{Sh} and Y_0 are the impedance measured with the line terminations short circuited and the admittance measured with the line terminations opened respectively.

The attenuation constant α is the real part of the propagation constant γ.

From the theory, it's well known that the propagation constant γ is calculated as follows:

$$\gamma = \alpha + j\beta = \sqrt{(R + jX)(G + jB)} \qquad (4)$$

In order to take into account the loss in the line, since G' usually is neglected, the distributed series resistance R' only is considered. This resistance can be approximated by treating the line as lossless and adding lumped resistances at both ends.

III. Measurements

The measurements were carried out with a vector network analyzer, model ZVRE 9 kHz-20 GHz by Rohde&Schwartz, to determine the fundamental line parameters versus frequency (R(f), L(f), C(f)).

The frequency range investigated is 25-200 kHz. With reference to the EN 50065-1 Standard, the frequency range investigated is 25 kHz - 200 kHz (including the fixed CENELEC range 95 kHz – 148.5 kHz).

Table 1 reports the data sheet of the cables under test.

Table 1: Data sheet of the cables under test

Nominal Cross-Section [Nr x mm^2]	Conductor Diameter [mm^2]	Insulation Thickness [mm]	Approx Screen Section [mm^2]	Max Overall Diam. [mm]
1 x 95	11.4	8.0	12	38.0
1 x 185	16.0	8.0	12	43.0

In Fig. 2 the termination of the cable under test is shown.

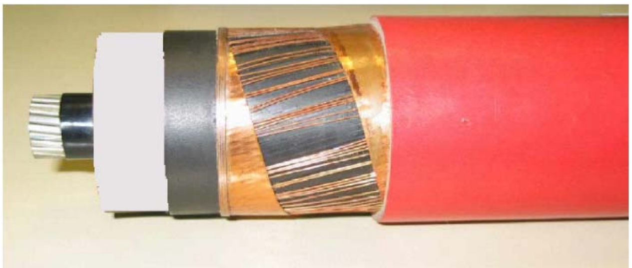


Fig. 2 - Photography of the cable termination

The measurements on MV cables present technical problems that don't exist in measurement on cables with small cross-sections.

In facts, there are technical difficulties to connect the cable end to the VNA for the great constructive and geometric

difference between the cable and the connection to the instrument with N type connector.
In consequence the contact-resistance appears between the cable under test and the instrument connector which value is comparable with the longitudinal resistance measured when short cable is used. For this reason, it's necessary to adopt cables whit an adequate length (>10 m).
Two types of measurements have been done: the first with the cable opened far end, to determine the open-circuit admittance Y_0 (cross parameters), the second with the cable short-circuited far end, to determine the short-circuit impedance Z_{sh} (longitudinal parameters).
From transmission line theory, the input impedance looking into a line with length L and termination load Z_L is:

$$\dot{Z}_{in} = \dot{Z}_C \frac{\dot{Z}_L + \dot{Z}_C \tan(\gamma \cdot L)}{\dot{Z}_C + \dot{Z}_L \tan(\gamma \cdot L)} \quad (5)$$

If the load terminal is short-circuited, i.e. $Z_L = 0$, (5) becomes:

$$\dot{Z}_{sh} = \dot{Z}_C \tan(\gamma \cdot L) \quad (6)$$

Similarly, if the load terminal is open-circuited, i.e. $Z_L \to \infty$, (5) becomes:

$$\dot{Y}_0 = \frac{1}{\dot{Z}_C \cot(\gamma \cdot L)} \quad (7)$$

From (6) and (7), finally follows:

$$\dot{Z}_C = \sqrt{\frac{\dot{Z}_{sh}}{\dot{Y}_0}} \quad (8)$$

The measurements have been performed over two different line configurations: the core-shield for single cable and the core-core transmission mode for double cable.
The measurement results are memorized by the VNA as sequence of complex data (2-dimensions vector), of the type:

$$\dot{Z}(f) = \mathrm{Re}(\dot{Z}(f)) + j\,\mathrm{Im}(\dot{Z}(f)) \quad (9)$$

$$\dot{Y}(f) = \mathrm{Re}(\dot{Y}(f)) + j\,\mathrm{Im}(\dot{Y}(f)) \quad (10)$$

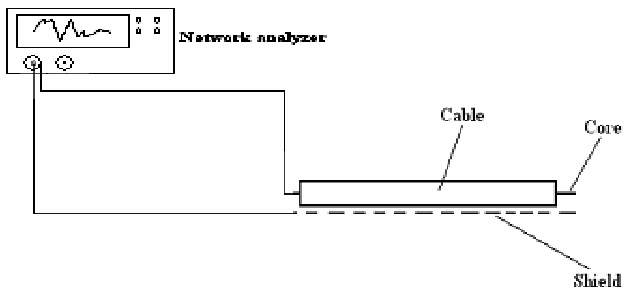
where f is the frequency, Z(f) is the complex impedance, Y(f) is the complex admittance, Re(·) and Im(·) are the real and imaginary parts respectively.
From the Y_0(f) values and in particular from the Y_0(f) phase trend, a capacitive behavior is deduced and the C(f) [F] values are derived from the imaginary part of Y_0 by the following formula:

$$C(f) = \frac{\mathrm{Im}[Y_0(f)]}{\omega} \quad (11)$$

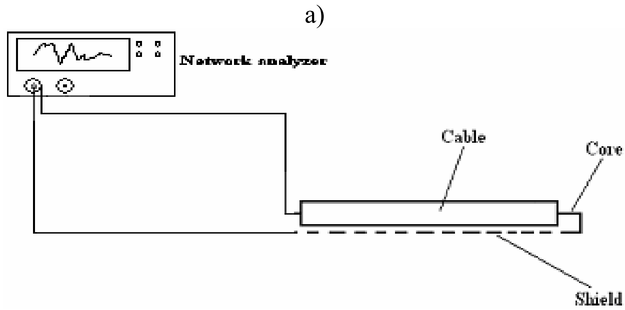
where $\omega = 2\pi f$ is the angular frequency [rad^{-1}].
From the Z_{sh}(f) values and in particular from the Z_{sh}(f) phase trend, an ohmic-inductive behavior of the impedance is deduced and the inductance L(f) [H] values are derived from the imaginary part of Z_{sh}(f) by the following formula:

$$L(f) = \frac{\mathrm{Im}[Z_{sh}(f)]}{\omega} \quad (12)$$

As regard the real part of Y_0(f) and Z_{sh}(f) these represent the dielectric and ohmic losses in the cable respectively. In particular the real part of Y_0(f) is named G(f) [S] as the real part of Z_{sh}(f) is named R(f) [Ω].
In Fig. 3 the measurement set-up for the determination of cross and longitudinal parameters of a single cable system is shown.



a)



b)

Fig. 3 – Measurement set up for single cable parameters: a) cross parameters; b) longitudinal parameters.

The attenuation α [Np/m] is the most important datum, because measures the effective capability of the line to transport a signal.
In the following figures (4,5), are shown the measurement results of Z_C for a single cable system and the attenuation vs frequency.

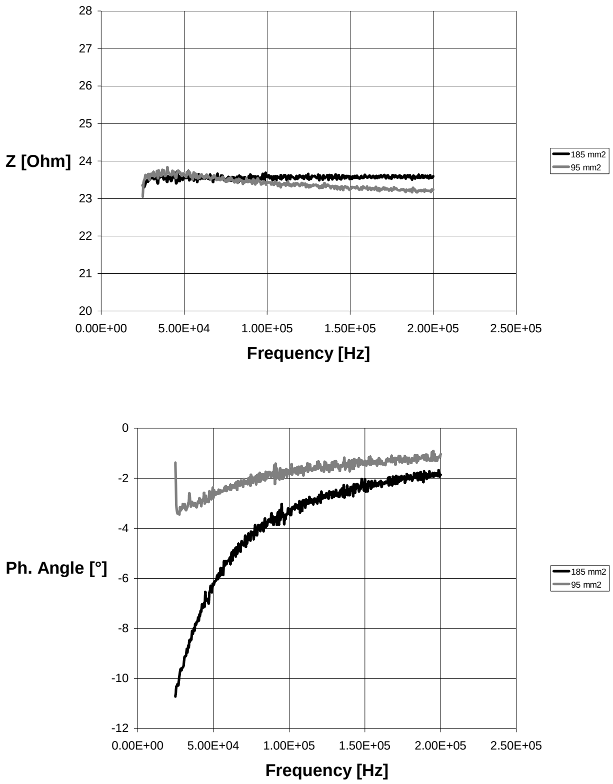


Fig. 4 – Magnitude (bottom) and phase angle (down) of characteristic impedance for a single cable system

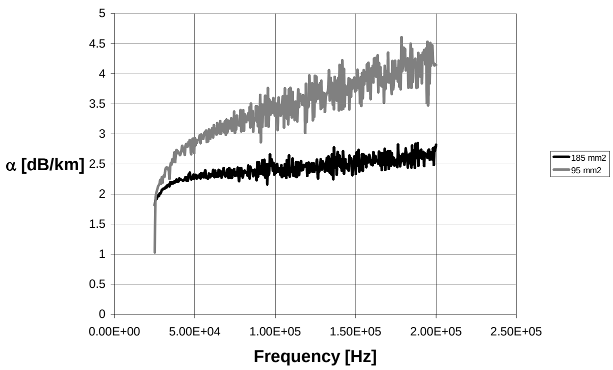


Fig. 5 - Kilometric attenuation for a single cable system

With reference to the above figures, it can be noted that the characteristic impedance Z_C is quite constant in the frequency range investigated, while the attenuation increase linearly in the frequency range and moreover depends by the cross-conductance.

In Fig. 6 the measurement set-up for the determination of cross and longitudinal parameters of a double cable system is shown.

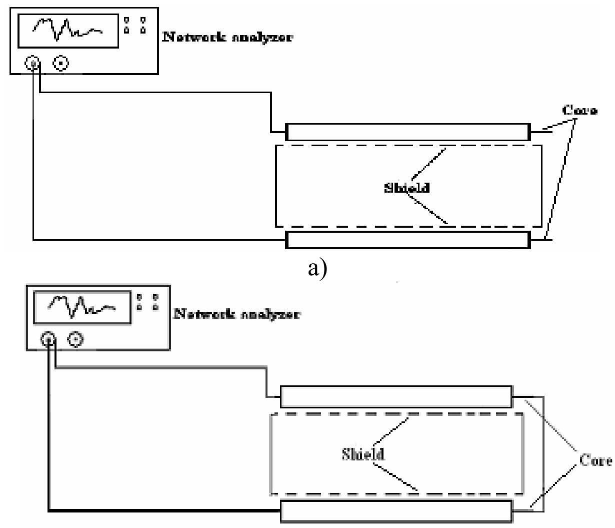


Fig. 6 – Measurement set up for double cable parameters: a) cross parameters; b) longitudinal parameters.

In the following figures (7 and 8), are shown the measurement results of Z_C for a double cable system, its phase angle and the attenuation vs frequency.

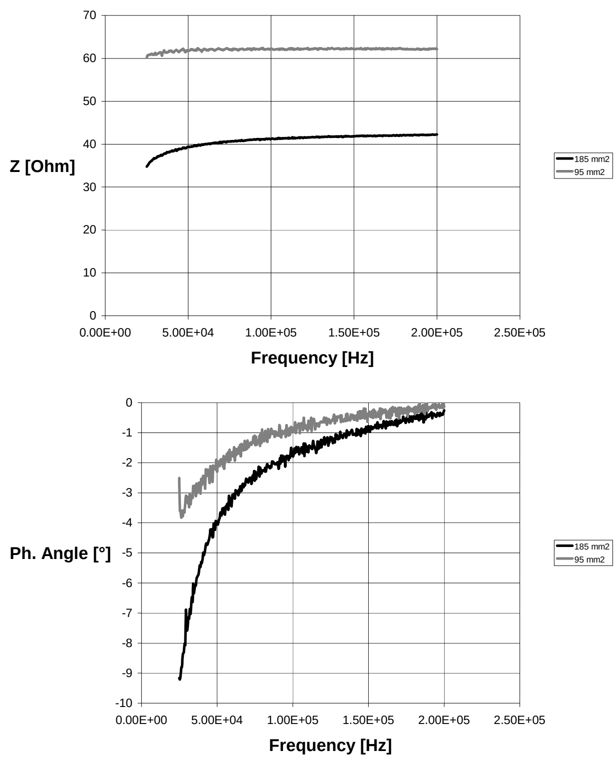


Fig. 7 – Magnitude (bottom) and phase angle (down) of characteristic impedance for a double cable system

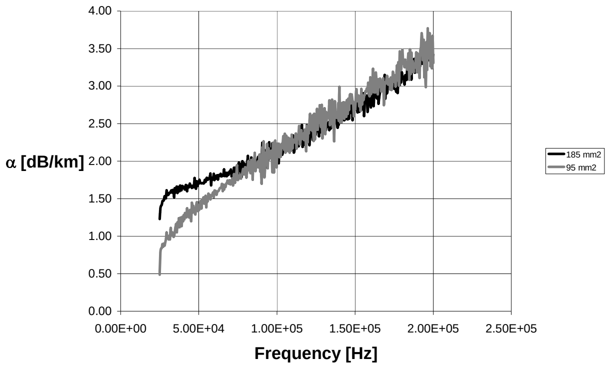


Fig. 8 – Kilometric attenuation for a double cable system

It can be noted that in this case the characteristic impedance is higher than the single cable system case. It also important to note that the influence of the cross conductance in the attenuation diagram is heaviest than the analogue diagram found for the single cable system.

IV. CONCLUSIONS

In this paper a characterization of MV cables was carried out by means of experimental tests on commonly used RG7H1R cables of two sections, 95 and 185 mm^2 with copper core and aluminum core respectively.
The main parameters, as characteristic impedance and kilometric attenuation, have been evaluated in the frequency range 25-200 kHz according to EN 50065-1 and for different transmission line configurations. It has been considered both single cable, signal injected between the core and the shield, and two cables with signal injected between their cores.

V. REFERENCES

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