Radiated Emission Associated with Power Line Communications on Low Voltage Buried Cable

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Abstract

The purpose of this paper is the study of the radiations due to the injection of power line communications (*PLC*) signals belonging to the frequency range $[1MHz - 30MHz]$ on a low voltage buried cable. An original model has been developed and simulated with the *NEC*4 code (*N*umerical *E*lectromagnetic *C*ode) to characterize the radiated emissions. The numerical results will be validated using experimental data. Besides, a definition of an electric coupling factor is proposed, a study of the propagating waves wavelengths and the energetic exchanges are detailed too.

Keywords

power line communications, radiated emissions, antenna theory, *NEC*4 code, electromagnetic fields measurement

I. Introduction

The possible use of the electrical low voltage network as a communication medium becomes very attractive as no additive cabling is necessary. The *PLC* signals are assumed to belong to a frequency range beginning at $1MHz$ up to $30MHz$ thus enabling the transmission of high data rates of the order of a few *Mbits/s* (internet, digital movies, ...) (see e.g. [dostert]).

The first developments of *PLC* networks in France will be located in urban areas where the transmission medium which is used more and more is the buried one. This specific choice is related to a will for networks protection against noises, storms and for obvious environmental esthetic reasons.

It is the reason why we are going to focus on the radiated emissions associated with *PLC* signals injected on a low voltage underground cable since many studies have already been done on overhead multiconductor lines (se e.g. [damore] [helier] [naredo]).

In the following section, we will present the studied cable and we will show why we have chosen a common mode propagation approach instead of a pure differential one. Then, an original model taking into account all the propagation phenomena and the ground properties will be presented.

Some numerical simulations based on the antenna theory will be done which will enable us to get some important informations about the propagating waves wavelengths above the ground, the energetic exchanges between the cable and the ground and we will finally introduce the coupling factor concept. All these simulation results will be compared to measurements done in real experimental conditions on a low voltage buried cable.

II. Characterization of the radiated emissions

The low voltage underground cable used in the French distribution grid is the *HN*33*S*33 cable depicted on figure 1 with table (1) detailing the associated caption.

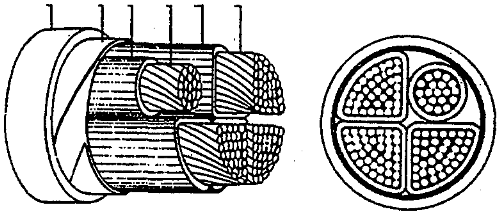

Fig. 1. Low voltage underground *HN*33*S*33 cable

1	Phase conductor(aluminium)
2	Chemically reticuled polyethylene(CRP)
3	Neutral conductor(aluminium)
4	Sheath of the neutral conductor
5	Shield(steely ribbon)
6	Exterior CRP sheath

(1)

In normal operational conditions, a signal injection is practised between the neutral conductor and a phase conductor thus creating a pure differential establishing mode. In fact, the steely ribbon in galvanic contact with the neutral conductor can be seen as a shield which will mask the majority of the radiated emissions coming from this previous propagation mode. Moreover, the neutral conductor is connected to the ground via metallic guides which will create a circulation of *PLC* signals in a secondary loop integrating the ground. It is the reason why we can suppose that the majority of the radiated emissions comes from a common mode propagation.

To take into account the ground, we can consider a coaxial model, the core representing the whole cable and the shield the ground. The ground will then present dielectric losses properties and the core is assumed to be a perfect conductor. The separation between the two previous materials is chemically reticuled polyethylene (*CRP*). The core radius corresponds to the equivalent cable radius and the shield radius has been taken in order of the penetration depth in the ground at $1MHz$. Figures 2 and 3 give our coaxial model shape.

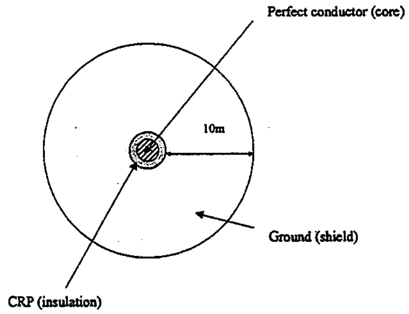

Fig. 2. Coaxial cable model into a common mode approach

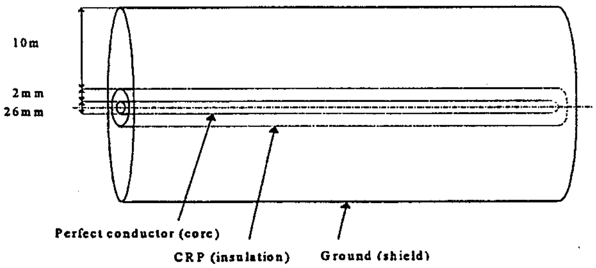

Fig. 3. Coaxial cable model into a common mode approach

III. Simulations based on the antenna theory

We have chosen the antenna theory as it is the most rigorous method for electromagnetic fields evaluation [burke1]. We used the $NEC4$ code implementing the antenna theory via the method of moments for radiating structures embedded in a lossy medium characterized by a relative permittivity and a finite conductivity [burke3]. The losses are taken into account using the Sommerfeld integrals.

The only assumption made in NEC is the thin wire hypothesis which assumes that all the wires radius must be much smaller than the injected signals wavelength λ_0. Hence, for a structure that can be modelled as a union of straight elementary segments, we have to spatially discretize it [burke2] with a step δ verifying condition (2).

$$\delta \leq \frac{\lambda_0}{\alpha} \tag{2}$$

where α is a weighting coefficient which can take typical values between 10 and 20.

In the following simulations, we took a monochromatic signal generator delivering an excitation like $E_0 \cos(2\pi f_0 t)$ with an internal impedance of 100Ω where $E_0 = 5V$ and $f_0 \in [1MHz...30MHz]$. We added a terminal resistive load of 100Ω too.

A. Simulation in a semi-infinite ground

In this section, we have considered a burial depth of $80cm$ which is the depth used by transport and distribution utilities for underground cables practical buring. Figure 4 illustrates the simulation model and the chosen observation line (OL) is given by equation (3).

$$OL = \left\{(x, y, z) \in R^3 \mid -70m \leq x \leq 70m, y = 0m, z = 2m\right\} \tag{3}$$

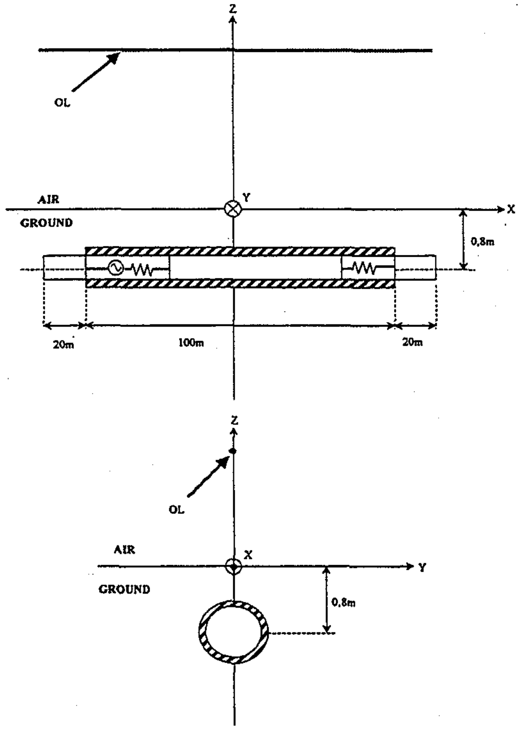

Fig. 4. Low voltage buried cable in a semi-infinite ground

For the given observation line defined by equation (3), we have calculated the electric and magnetic fields distributions for the three following typical frequencies $4MHz$, $10MHz$ and $17MHz$. The obtained simulations results are depicted on figure 5 (resp. 6) for the electric (resp. magnetic) field.

We can clearly see on figures 5 and 6 that we have a non tranverse electromagnetic (TEM) propagation mode and we were right for not having applied some less rigorous and faster methods such as the quasi-static theory or the transmission line theory [baraton]. From a theoretical point of view, the non TEM propagation is related to the external coaxial model radius ($10m$) which is not neglictible compared to the injected signals wavelengths ($10m$ at $30MHz$ in free space).

Another interesting note is relative to the visible oscillations of the main components of the electric and magnetic fields. As there is an impedance mismatch at the terminal port, we have some standing waves phenomenon such as the distance between two local minima (or maxima) is quite equal to half the wavelength of the injected signal. For example, for $4MHz$, $10MHz$ and $17MHz$, the associated freespace wavelengths are $75m$, $30m$ and $18m$, respectively. Considering figures 5 and 6, we approximately find for the same frequencies, $72m$, $28m$ and $20m$ for the wavelengths. These values are not exactly the same as freespace values as one part of the radiated emissions takes place in the ground which characteristics are different from the vacuum properties.

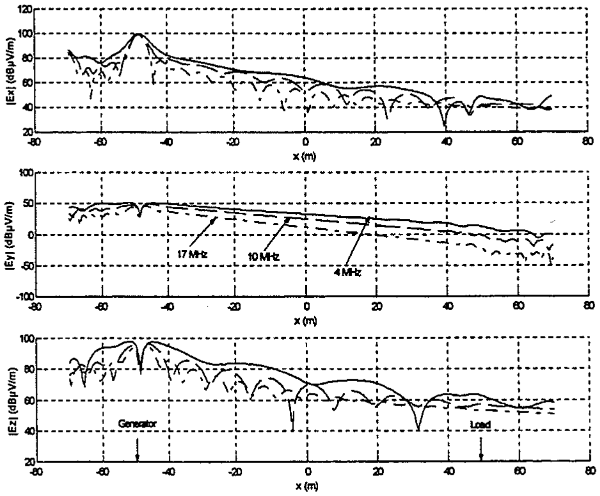

Fig. 5. Electric fields components according to OL

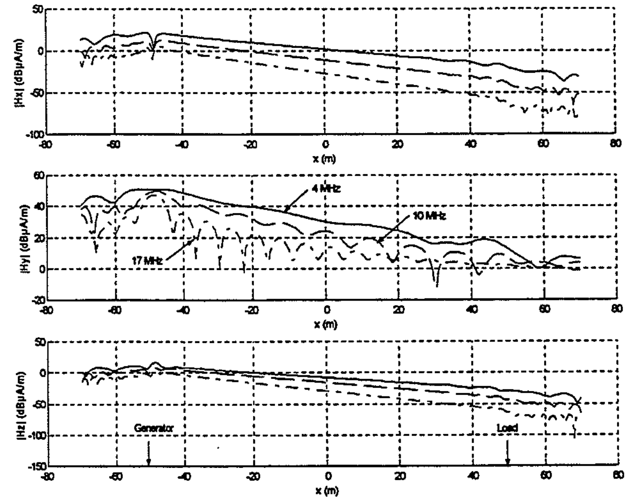

Fig. 6. Magnetic field components according to OL

B. Energetic exchanges

By using $NEC4$, it is possible to get the energetic exchanges between the low voltage buried cable and the ground. For example, we present in table (4) the power budget for the three typical frequencies $4MHz$, $10MHz$ and $17MHz$ where f, IP, RP, WL and E denote the studied frequency, the injected power, the radiated power, the wire loss and the efficiency respectively.

f (MHz)	4	10	17
IP (mW/dBm)	41,1/16,1	53,4/17,3	58,8/17,7
RP (mW/dBm)	26,8/14,3	29,2/14,7	30,5/14,8
WL (mW/dBm)	14,3/11,5	24,2/13,8	28,4/14,5
E (%)	65,21	54,76	51,77

(4)

The observation of the power budget of table (4) let us to conclude that the efficiency coefficient, which is defined as $E = RP/IP$, globally decreases when frequency increases. Roughtly speaking, this means that higher the frequency is and lower the radiated emissions are important for the common mode propagation for this kind of cable.

C. Coupling factor

The coupling factor κ represents a local transfer function between the electric field magnitude E and the injected power P_i, these values obviously depend on the studied frequency f. The definition of κ is given according to equation (5).

$$\kappa(f) = \frac{E(f)}{P_i(f)} \tag{5}$$

Figure 7 shows, for example, the evolution of the coupling factor in the frequency range $[1MHz - 30MHz]$ for three observation points located at $(x, y, z) = (-20m, 0m, 2m)$, $(x, y, z) = (0m, 0m, 2m)$ and $(x, y, z) = (20m, 0m, 2m)$ which are located at a distance from the injection point of $30m$, $50m$ and $70m$, respectively. These results are for a common mode propagation only and not a differential mode propagation.

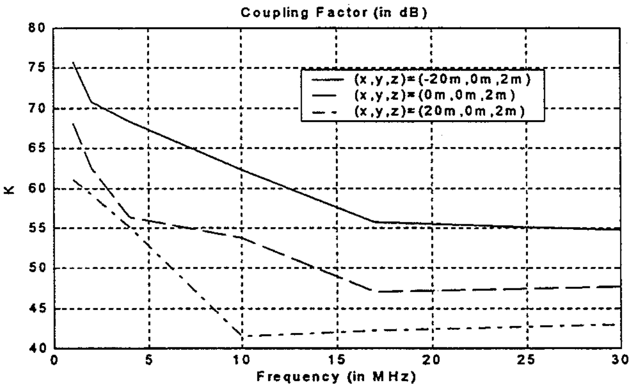

Fig. 7. Calculated coupling factor

We can check that the electric coupling factor is a decreasing function of frequency specially when we are near the injection point, typically between $30m$ and $50m$. Besides, we can note that the dynamics of the coupling factor values is spanned, for one given given frequency, between $13dB$ and $20dB$.

IV. Experimental validation

Our experiment took place in a piece of field located in Paris suburb. The site has been chosen for not having any cable (telecomunications, electricity, water, ...) in its near neighbourhood. Hence, there was no parasit coupling with our experimental cable coming from other near cables. The cable was a $HN33S33$ one of $100m$ long and has been buried at a $80cm$ depth. Only its extremities were embedded in air. To take into account a common mode propagation, we add near the two cable extremities two metallic guides of $1m$ long. Figure 8 summarizes the general configuration of the experimentation. The measurement of the three electric components has been done by using a dipole antenna and a $HFH2Z1$ rod antenna (Rohde&Schwarz) whereas this has been done for the magnetic field by using a $HFH2Z2$ loop antenna (Rohde&Schwarz) connected to a $HP4395A$ (Hewlett-Packard) spectrum analyzer.

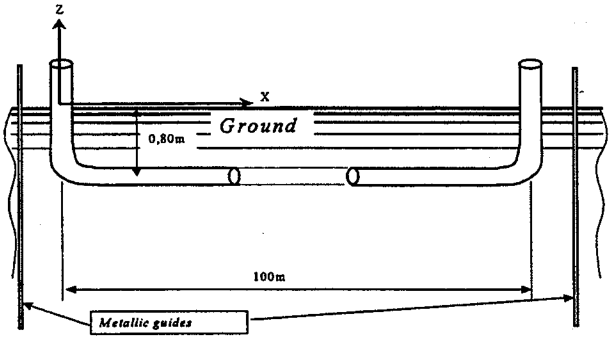

Fig. 8. Description of the measurement set-up

To compare the experimental data with the simulated data, we have considered the following measurement line (ML) defined by equation (6) and refering to figure 8.

$$ML = \left\{(x, y, z) \in R^3 \mid 0m \leq x \leq 100m, y = 0m, z = 1.5m\right\} \qquad (6)$$

We obtained for example the results of figure 9 for the vertical electric component for a frequency of $17MHz$ and an injected power of $15dBm$ delivered by a Rohde&Schwarz generator.

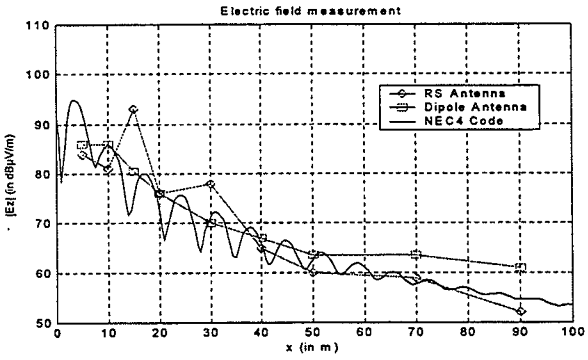

Fig. 9. Simulated and measurement electric field

We can note that the difference existing between the simulation results and experimental data does not exceed $7dB$ in average. This is a clear validation of our physical coaxial model to simulate the radiations coming from a common mode propagation on the low voltage buried cable.

V. Conclusions

In this paper, some numerical simulations have been done for characterising the radiated emissions due to PLC signals. These PLC signals are assumed to belonging to a frequency range beginning at $1MHz$ up to $30MHz$. We have focused our study on a low voltage buried cable as this medium is increasingly used on the low voltage grid.

These simulations enabled us to get some values of the electric coupling factor at one given frequency. Hence, knowing the value of this coupling factor and the injected power on a power line network, we can give an estimate of the electric radiated emissions related to the injection of PLC signals. Let us recall that the coupling factor results are relative to a common mode propagation only.

The simulations results have been validated by experimental data. The measurement have been practised on a $HN33S33$ cable buried in real conditions.

To refine our study, one could study the radiations of this cable for a differential mode injection to deduce an estimate of a longitudinal conversion loss (LCL).

VI. Acknowledgement

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