参考資料８－１

平成１７年８月１８日

高速電力線搬送通信に関する研究会（参考資料）

参考資料 7-2　【Indoor PLC に係わる欧州論文の紹介】補足説明

林政克（日経ラジオ社）

欧州のＰＬＣ開発プロジェクト「ＯＰＥＲＡ」のサイトに掲載された論文について、全文を紹介致します。

「**A Technique to Reduce Electromagnetic Field Radiated by Indoor PLC Systems**」…（別紙）

出典：http://www.ist-opera.org/press_clippings.html

（以下、参考資料７－２の記述を再録）

論文著者は、Switzerland・ Germany・ Franceの連名。

論文では、「（被干渉設備までの）距離が短く、使用条件の設定も不可能なことから、屋外配線によるＰＬＣに比べ、屋内配線によるＰＬＣの方がより厳しい」と指摘している。

この論文から、ＰＬＣの屋内放射における屋内の被干渉設備へ配慮する立場が窺える。

以上

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A Technique to Reduce Electromagnetic Field Radiated by Indoor PLC Systems

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Abstract: This paper proposes a technique aiming at reducing significantly the electromagnetic field radiated by indoor PLC signals, while not affecting the PLC signal itself. The basic idea is to take advantage of the additional ground conductor and inject a signal similar to the PLC signal into the ground-neutral line, but with a reversed phase. As a result, both the overall antenna mode- and transmission line mode-currents are significantly reduced, as well as the radiated electromagnetic fields.

Numerical simulations obtained using NEC (Numerical Electromagnetics Code), as well as experimental measurements are also presented. It is shown that the proposed technique allows for a significant reduction (up to 20 dB) of the PLC electromagnetic radiation in the considered indoor frequency range (10-30 MHz).

Keywords: Power Line Communications, electromagnetic radiation, mitigation, EMC.

INTRODUCTION

Distribution power lines have been used for decades to transmit specific data pertaining to the network operation or to various services offered by electrical utilities to their customers.

In the last few years, feasibility studies have been performed in various countries to demonstrate the possibility of using the low voltage distribution network to provide data transmission services to individual customers at frequencies up to 30 MHz (see e.g. [1], [2]). PLC transmission systems in the frequency band extending from 1 to 30 MHz present various and quite complex EMC problems (e.g. [3]–[7]). One of the main problems is the emission of electromagnetic noise, which can interfere with services such as public and amateur radio.

Several techniques have been proposed to mitigate electromagnetic interferences caused by PLC systems in outdoor environment, as discussed below. However, to the best of our knowledge, the mitigation of indoor radiation has not been addressed in the litterature, although generally more critical compared with outdoor radiation (unshielded conductors and short distances). Dostert, in [8], proposes measures of network conditioning to reduce electromagnetic interferences, however, he states: “Unfortunately the above results cannot be transferred to the indoor network. High speed PLC within buildings will remain a severe EMC challenge, because there are no possibilities for conditioning”.

The aim of this paper is to present a simple technique to mitigate PLC radiation within buildings and validate it through experimental measurements.

1. Description of the proposed technique

We propose a method to reduce the electromagnetic interferences associated with PLC signals along indoor low voltage networks [9]. The method is specifically developed for indoor applications (see Fig. 1) and applies to the general bi-directional data transmission systems (downstream and upstream).

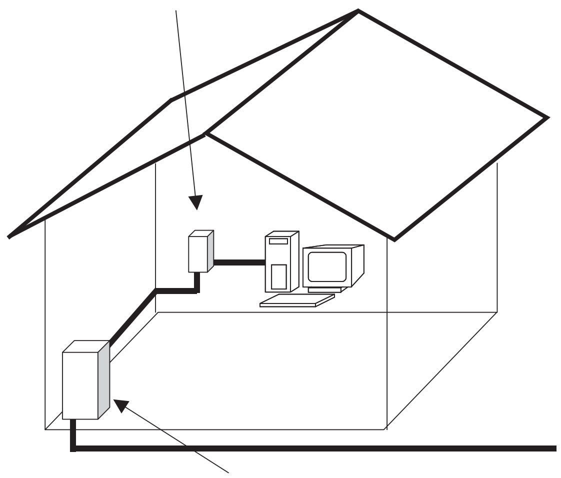

Fig. 1. Illustration of the indoor PLC environment

In PLC applications, the signals are coupled to the line formed by the phase and the neutral conductors. In Fig. 2, the low voltage grid is schematically represented by a single cable.

In this case, the current flowing along the line (formed by the phase and the neutral conductors) can be divided into two components called antenna mode and transmission line mode [10], respectively. Both these modes radiate electromagnetic field. However, because the current flows in the same direction in

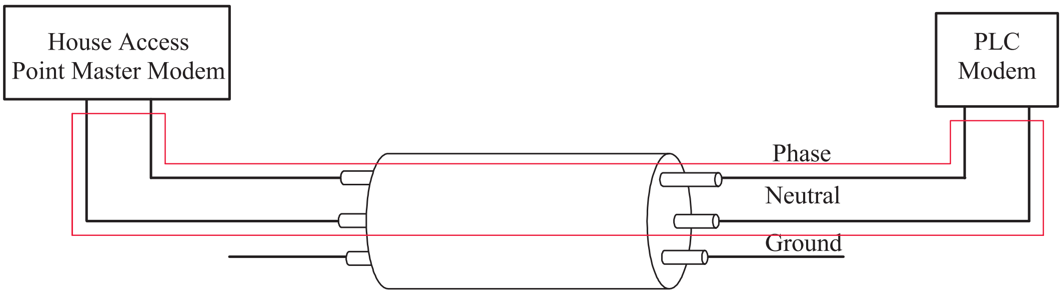

Fig. 2. Classical coupling of PLC signals onto an indoor low voltage network

antenna mode, the field radiation is much higher than that of the transmission line mode.

The idea is to take advantage of the often present additional ground conductor and inject an auxiliary signal with the aim of reducing the overall antenna mode and transmission line currents. The auxiliary signal, injected into the line formed by the ground and the neutral conductors, has the same amplitude and shape as the PLC signal but with an opposite phase. Mathematically, if the original PLC signal transmitted through the line formed by the phase and the neutral conductors is given by $S_1 = s(\omega)e^{j\alpha(\omega)}$, the signal injected into the line formed by the ground and neutral conductors would be $S_2 = s(\omega)e^{j\alpha(\omega)+j\pi}$.

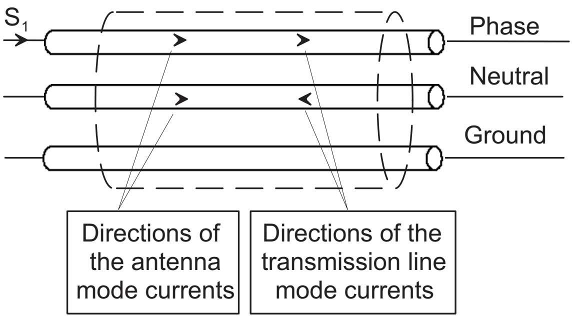

Fig. 3. Illustration of antenna mode current and transmission line mode current components

The resulting current distribution is qualitatively illustrated in Fig. 4. As it can be seen schematically from the figure, both antenna mode and transmission line mode current components associated with the two signals S_1 and S_2 tend to cancel each other, therefore reducing the associated electromagnetic field.

The performance of the proposed technique will improve when the two lines (phase-neutral and ground-neutral) are terminated by the same impedances. For this reason, the proposed system includes terminal matching impedances in series with low-frequency decoupling capacitors.

2. Test of the proposed technique

2.1. Configuration

To study the performance of the proposed technique, we have considered a simple test configuration consisting of a single horizontal power cable of 2.7 m length, located 1 m above ground. The PLC signals are injected into the cable considering

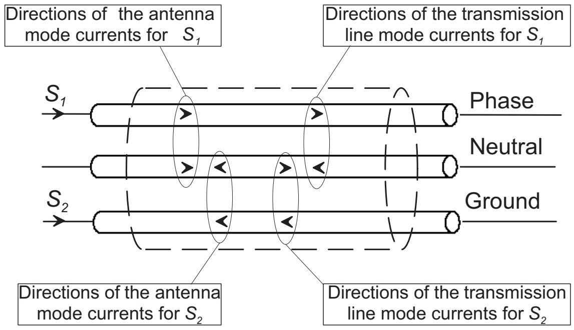

Fig. 4. Distribution of the transmission line mode and the antenna mode currents resulting from the proposed technique

1) a classical coupling (Fig. 5a) in which the signal is injected between the phase and the neutral of the power cable,
2) the proposed coupling method without terminating impedances (Fig. 5b) in which an opposite-phase signal is injected into the line formed by the ground conductor and the neutral; and, finally,
3) the proposed coupling method is considered with the ground-neutral line terminated on an impedance equal to that of the phase-neutral line (Fig. 5c).

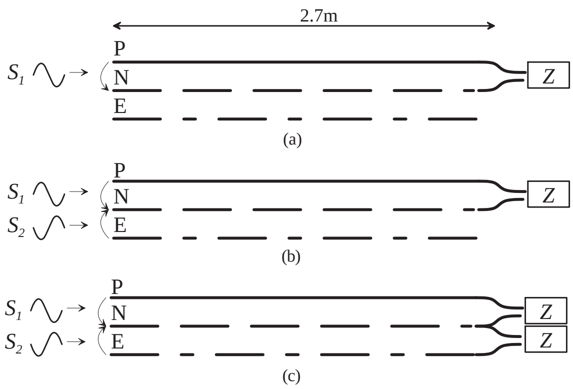

Fig. 5. Test configurations: (a) classical coupling of PLC signal to the line formed by the phase and neutral conductors; (b) proposed coupling, ground-neutral line open-circuited; and (c) proposed coupling with ground-neutral line terminated on an impedance equal to that of the phase-neutral line. The impedance used in numerical simulations and in measurements $Z = 50\ \Omega$.

2.2. Numerical simulations

We have used the well-known Numerical Electromagnetics Code (NEC-2) [11], [12], which solves the electromagnetic field integral equation in the frequency domain using the method of moments to test the proposed method.

Figure 6 shows the magnetic field calculated at a distance of 1 m from the line center for the three considered configurations. It can be seen that the injection of the auxiliary signal into the ground-neutral line results in a magnetic field reduction of about 20 dB in the considered frequency range. It can also be seen that a proper termination of the ground-neutral line will result in additional significant reduction of the radiation.

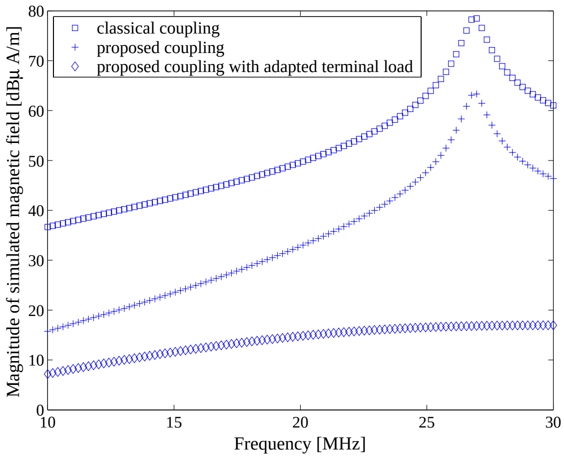

Fig. 6. Simulated magnetic fields

2.3. Experimental Results

Experimental tests were also carried out in the semi-anechoic chamber of the EMC Laboratory of the Swiss Federal Institute of Technology in Lausanne. We performed our measurements on the simple test network composed of a 2.7 m power cable with three conductors (phase-neutral-ground) located at a height of 1 m above ground (see Fig. 5).

A high frequency generator was used to inject a harmonic signal of 3 V amplitude with frequencies sweeping from 10 to 30 MHz through a power split which allowed us to have two similar PLC signals with an opposite phase. We measured the three components of the radiated magnetic field using a loop antenna connected to a spectrum analyser. The antenna was located 1 m away from the line center and with the same height as the cable. This measurement set-up was in accordance with the one used for the simulation.

Figure 7 presents the measured magnetic field, for the three considered configurations (Fig. 5). It can be seen that the experimental results corroborate qualitatively the numerical simulations and show the same trends. Differences between simulations and measurements can be explained considering the simplifying assumptions in the model (simplified representation of the cable, neglecting the conductors' insulating jacket), as well as experimental uncertainties.

3. CONCLUSION

This paper proposes a method to reduce the electromagnetic interferences associated with PLC signals along indoor low voltage networks. The method is specifically developed for indoor applications and applies to uni-directional and bi-directional data transmission systems (downstream and upstream).

The proposed method consists of the injection of a signal similar to the PLC signal into the ground-neutral line but with an opposite phase. The efficiency of the proposed method has been demonstrated by numerical simulations performed using NEC.

In addition, experimental data obtained on a test network have confirmed that the proposed technique allows for a significant reduction (up to 20 dB) of the PLC electromagnetic radiation in the considered frequency range.

It is also shown that the performance of the proposed technique increases when the ground-neutral line is terminated on an impedance equal to that of the PLC modem.

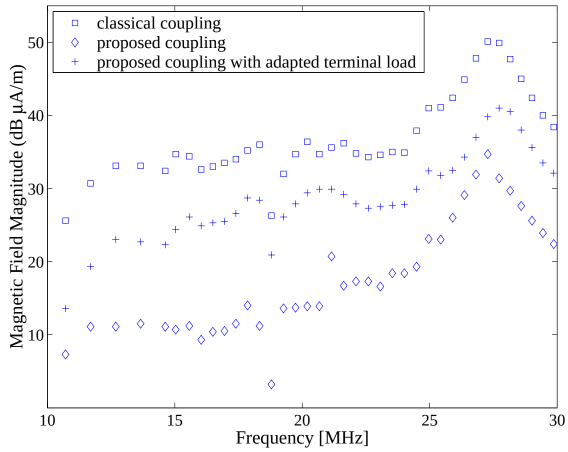

Fig. 7. Magnetic field radiated by an indoor PLC signal according to test configurations described in Fig. 5.

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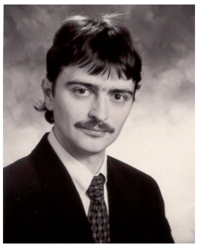

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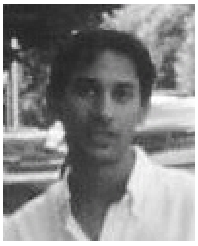

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