Секция 6

ИСПОЛЬЗОВАНИЕ НИЗКОВОЛЬТНЫХ СЕТЕЙ ДЛЯ ПЕРЕДАЧИ ДАННЫХ
POWER LINE COMMUNICATION

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EMC PROBLEMS OF POWER LINE COMMUNICATION (PLC) SYSTEMS

Abstract

Power line Communication is a new emerging technique in the domain of transmission of information on LV power lines which operates in the frequency range 1 to 30 MHz. It should allow bit rates up to some Mbits per second and may be used for the transmission of telephone services, of internet data, of control operations for Utilities or in Houses (Domotic), etc, This technique meets however with several difficult problems with regard to its characteristics, particularly with regard to EMC. Aim of the paper is to give an summarising overview on the specific EMC problems of PLC. A critical one is the emission of EM fields which could disturb radio services in the same frequency band.

1. Short history of the mains signalling systems

The idea of using the distribution power system also for the transmission of signals – under the general term of "Mains signalling " - appeared for the first time by the end of the 19th century when two French engineers took 1898 a patent on this invention. The practical application of this idea started in the 20th with a French multifrequency Ripple Control System but a real expansion of this technique took place after 1950. "Ripple Control" works in the low frequency range 110 to ca 1000 Hz , enjoyed worldwide a great success and became and is still now a normal network equipment. There are installed several thousands of systems and probably ca 30 to 40 Mio receivers. Ripple Control Systems are narrowband one way systems from the substations to the users. In the 70th several attempts were made with so called "Power Line Carrier" systems in the kHz frequency range 3 to 150 kHz, for two ways systems but with a quite limited success. In the 90th, the tremendous development of electronics and of the telecommunication techniques allowed a new start in the MHz frequency range for new systems and new broadband applications with "Power Line Communication" (PLC) systems. They are still in course of development [1].

2. Topology of PLC systems

Taking into consideration – as explained in the following chapters - on one hand the high frequencies allowing a broad frequency band necessary for the intended high speed applications, on the other hand the strong signal attenuation on the lines at these frequencies , it appears that a satisfactory signal transmission is possible mainly on the Low Voltage (LV) level. Two types of systems should be considered (see Figure 1)
- outdoor on the supply power lines: "Access systems" for Utilities purposes
- indoor in buildings: "In House systems" for private purposes (whereby there is to note that Utilities can also have to carry out functions inside the houses).

Figure 1 represents a classical European network with a star structure. Generally a transformer supply several houses (or one big professional building). Outdoor lines are constituted of 3ϕ cables in towns or also of overhead lines on the countryside. The wiring inside the houses is made of simple 2ϕ or 3ϕ +N conductors (US or Japanese networks have a quite different structure). Practically the LV network is very difficult to assess in the MHz range: there are very different configurations, the load varies continuously and most of the PLC characteristics must be considered statistically. The high frequency leads to resonance effects.

The backbone in Figure 1 is a classical broadband channel: control cable of the utility, radio link, TV cable, etc,

In the case that the length of the LV line ex ceeds the signal range , repeaters and gate ways have to be installed .

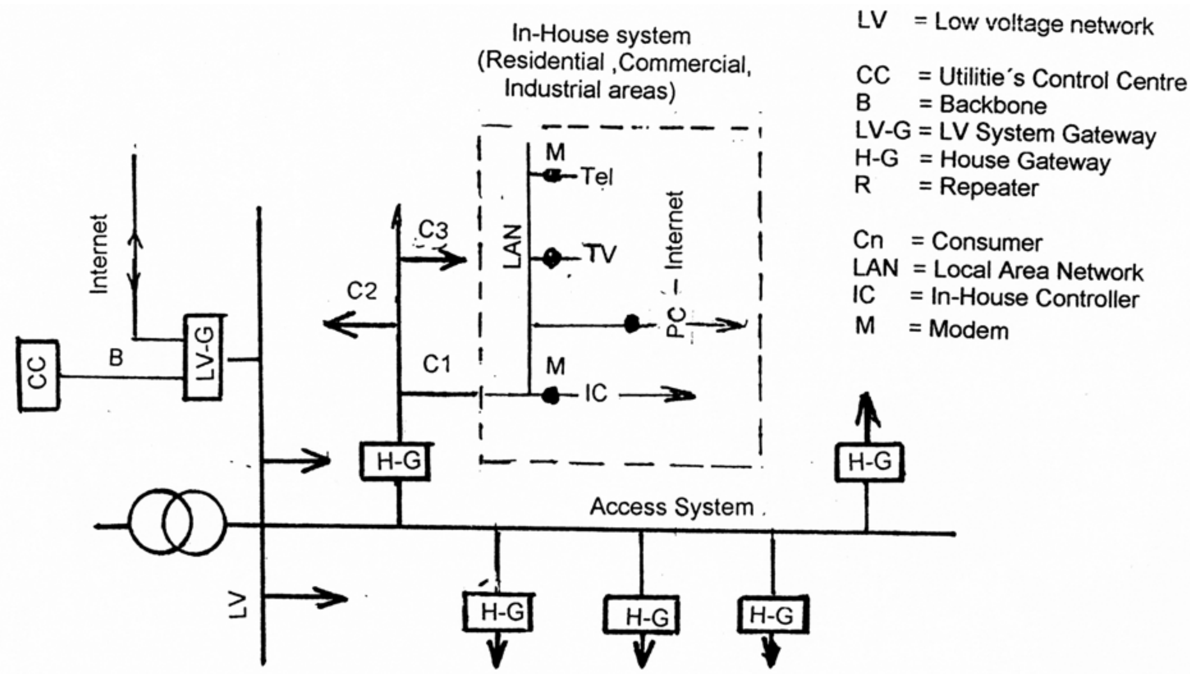


Fig 1. Powerline communication systems
. Structure of an Access System for Utilities
.Stucture of an In-House System for a consumer

3. Applications of PLC

PLC Systems should allow through the power lines new services which were not possible earlier. The promoters of PLC thinks at a lot of different applications: They require a high reliability of the communication system which has to be reflected in the EMC requirements e.g.:
- for Utilities: load control, remote meter reading, network automation, etc, ...
- for Internet providers: Internet services
- for Telephone operators: telephone transmission on the "Last mile"
- for In-House users: a LNA for computer systems, for domestic services (Domotic),...

Most of them are two ways services, downwards from a central control point to the application or upwards from the application to the central point. A complication is due to the fact that several applications can take place simultaneously.

4. EMC Problems of PLC Systems

Mains signalling in general, PLC systems in particular , are quite complicated systems , the design and operation of which have to consider numerous aspects. The following list shows the ones related to EMC, either conducted effects in the network or radiated effects :

- allocation of frequency bands and appropriate frequencies
- transmission characteristics and attenuation of the signals on the lines
- limited noise level of external sources
- no disturbance of network devices by the conducted signals
- no disturbance due to radiated fields
- no mutual influence between systems
- response level of the receiving devices
- permissible / limitation of the signal level
- signal modulation and coding

In the following chapters it will be given some basic information on these aspects. Thereby there is to remember that they cannot be considered independently but one may influence the others: e.g. the signal level shall be higher than the noise level but not so high that the radiated field disturbs the radio services. Signal modulation and coding are determinant for the system reliability. It must be remembered that there is also to take into consideration the intended applications and - this is not in the framework of this paper - the economic aspects.

5. Main technical characteristics

The following information refers to basic principles and published material. Manufactures do not mostly disclose technical details. The information is presented in very different manners and one of the aims of this paper is to shows it i more systematically. Because of the diversity of the references, the values given in the paper may not be considered as fully founded but should serve more as guidance.

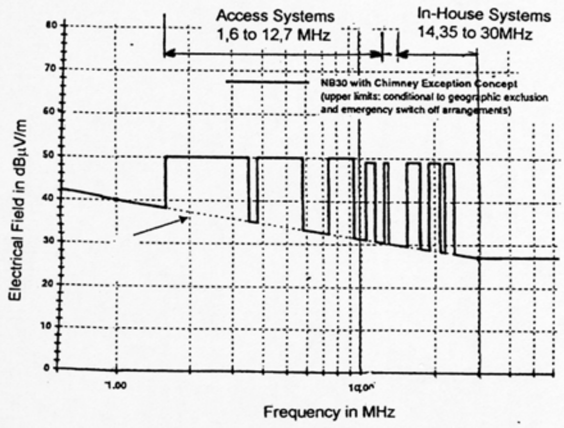
The technical values are generally given with two kinds of units:
- for narrow band / single frequencies values directly with their magnitude e.g. V/m or dB/Vm
- for broad band values when an integration over the band width is necessary with a reference value per Hz e.g. P mW/Hz or dBPm/Hz.

The measurements are or should be referred to CISPR 16-1 for Peak values, B= 9 kHz, an artificial network 50Ω50Ω /50µ H (or to the characteristics of the PLC system)

5.1 Frequency

PLC systems need a quite broad frequency band in order to allow the intended high speed functions and are located in the range 1 to 30 MHz.

Three problems:
- the frequency range is allocated by the ITU to Short wave radio services : SW broadcast, Safety services, Amateur Radio, and these frequencies shall be avoided



Band Start (kHz)	1810	3500	7000	10100	14000	18068	21000	24890	28000
Band Stop (kHz)	1850	3800	7100	10150	14350	18168	21450	24990	29700

International Amateur Radio Bands.

Fig. 2. PLC Frequency allocation and allowed Field Radiation with Chimney Exceptions according to the German NB30 (bottom : Amateur Radio Bands)

- there is avoid interference's between Address and In-house systems; a solution is to allocate separate frequency band to each application

- radiated EM fields could disturb the reception of radio broadcast or other services in the same frequency range.

The last problem is a serious one and is dealt with more in detail in chapter 5.5. The two first problems lead to the frequency spectrum represented on figure 2.

5.2 Signal Transmission

The great diversity of the networks and load conditions makes it very difficult to calculate the signal voltage transmission at the radio frequencies in the 50/60 Hz power systems.

Practical statistical measurements give a reference with which range of attenuation the signals are transmitted. Figure 3 (upper curve) shows as example the voltage attenuation on a power cable of 300m in function of the frequency: the voltage drop is in the range of 20 dB at 1MHz, of 80 dB at 20 MHz.

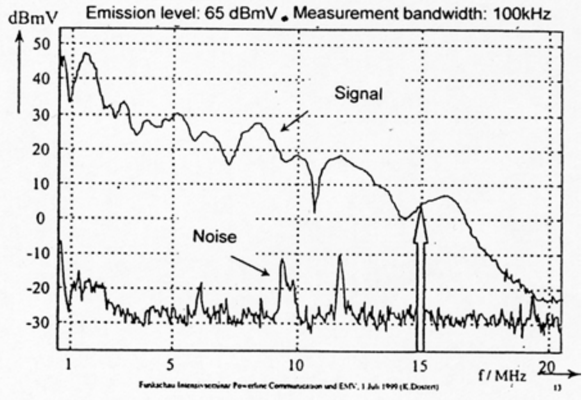


Fig. 3 Signal Voltage attenuation and noise on a 300 m cable

For a first approximation it can be reckoned with the following order of magnitude.

Type of line	Attenuation 1 to 30 MHz	Range of use
Address area:		
Cable	40 to 80 dB	300m
Overhead	40 to 80 dB !	300m ?
In-house area	up to 80 dB	ca 50m

When the necessary response voltage is not available, repeaters are necessary. Gateways may also be necessary between supply lines and in-house lines.

5.3 Noise level/Conducted disturbances on the LV network

The noise level on the lines is determining for the modems. Fig. 3 (lower curve) shows an example of the noise level on a supply cable. There are three kinds of disturbances to differentiate :
- a continuous broad band noise (white noise)
- narrow band "peaks"(single frequencies)
- pulses (which are not recorded on figure 3).

Measurement of noise depends on several factors: the bandwidth and the time constant of the measuring instrument, peak or quasi peak or average value, ...This makes comparative measurements difficult . It should be appropriate to standardise the measurement method, e.g. according CISPR 16 (bandwidth 9 kHz, peak value). From a general viewpoint it seems that it may be considered a range of:
- Broad band noise (B = 100 KHz, peak value): ca 30 to 40 dB µV
(referred to 9 kHz - the frequency ratio is not well known for this kinds of noise: ca ≤20dB µV resp. ≤30 dBµV ??)
- Narrow band noise up to 50 to 60 dBµV

Measurements in buildings shows noise levels in the same range of magnitude. It seems that similar levels have been registered in computer networks.

5.4 Limitation of the signal level with regard to the disturbance of other network items

PLC systems should not disturb other devices connected to the same network. The immunity of such devices against conducted "noise" in the frequency range 0,15 to 80 MHz is specified in the EMC Generic standards – or in CISPR 24 for ITE – to 3 Vrms not modulated. This is much more than the PLC signal levels (see below paragraph 5.6) and there is no danger of such disturbances.

5.5 Limitation of the signal level with regard to radiated fields

The PLC voltages and currents circulating in the LV lines radiate EM fields which could interfere with the radio services in the same frequency range. In fact the range 1 - 30 MHz , respectively the corresponding wavelengths 300 – 10m corresponds to the SW broadcast bands and with other frequencies reserved by the IUT for other services like alarm, police, etc,... Of course their function shall not be disturbed by PLC systems and this is the main concern of the relevant authorities and users. Within the context of this summarising paper only general information will be given on this subject , which is dealt more in detail in other contributions.[2] [4]

Some mains features:
- each conductor radiates electric and magnetic fields. When two conductors with opposite currents are very near the one to the other , the resulting field is very low, negligible.
-if there is some distance between conductors , a certain field results from the asymmetry between the two components. This is the case with power cables 3ϕ +(N+G) in the out door area particularly when the **N** conductor is grounded. The asymmetry is even stronger with overhead lines.

An asymmetry occurs also inside a building and a room due to the "wild" configuration of the internal wiring, also of the outlet, the domestic devices. etc, ...

Limits for the PLC signals are given for the time being in two forms: as limits for the radiated field or as limit for the signal level in the network Figure 4 shows the allowed limits for the fields radiated by PLC signals specified by different national authorities . The UK requirements are very severe, the US requirements more relaxed.

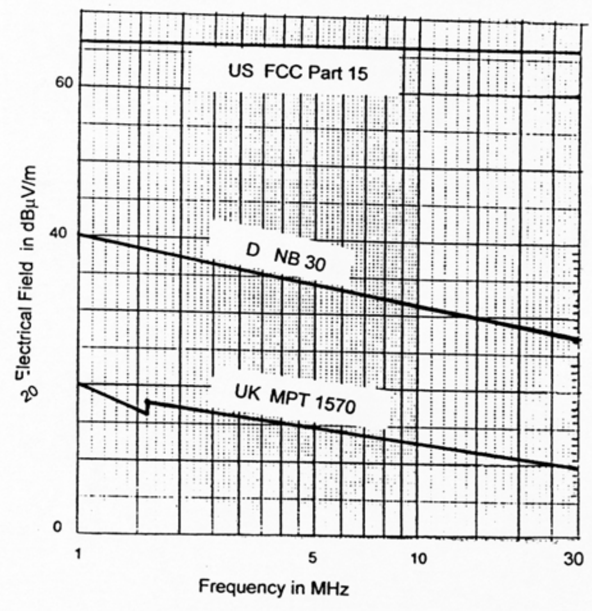


Fig.4. Radiated field limits in the UK, In Germany and in the USA

Before installing a new PLC system it is appropriate to asses the field it can produce. As for power cables the fields created by PLC systems could be calculated [2],[4] . However, practically, it appears that, compared to direct measurements of the electrical fields, the calculations gives too high values. This may be due to the fact that near to the cables we are not in the far field region. In buildings, the configuration of the wiring is so complicated that practically only statistical measurements are practicable. Generally further statistical investigations seem necessary. Of interest are the disturbing fields at distances of 1, 3, max 10m from the power lines or inside the rooms.

In order to estimate more easily these fields a simplified is proposed, to use a transfer function called "coupling factor" . It can be defined as the ratio

$$kE = \frac{E(f) \text{ Electrical field in V/m}}{U(f) \text{ Injected signal voltage in V}}$$

Practically in this frequency range, it is easier to measure the magnetic field and to convert it into the electrical field by multiplying it with the free space impedance Zo (377Ω)

$E(f)\mu V/m = H(f)\mu\ A/m \times Zo$ or

$E(f)\ dB\mu\ V = K(f)\ dB\mu\ A/m +51{,}5dB$

Note: Another proposal is to relate the coupling factor to the injected power but this method seems less easys for measurements on site.

Figure 5 gives an example of measurements of the coupling factor. Practically there are great variations of this factor due possibly to resonance effects which make the prediction of the fields quite unprecise.

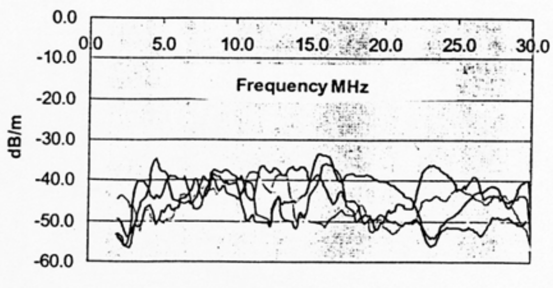


Fig. 5 Voltage Coupling factor near an Individual house

For a first approximate approach , the following coupling factors may be applied:

.power cables in outdoor areas : -35 to -55 dB
.indoor areas : -20 to 40dB(?)

5.3 Signal modulation and coding

The modulation method of the signals and the coding of the commands are generally not classified as EMC problems, but as they are closely related to network disturbances, they will be briefly considered. For more details it should be referred to the specialised literature.

As for the modulation method, with regard to the variable signal transmission conditions and the immunity toward impulse disturbances only broadband methods with frequency multiplexing come into consideration. The OFMD (Orthogonal Frequency Division Multiplexing) modulation seems to be the preferred one. It consists of subdividing the available spectrum in a high number of subchannels and to transmit the data simultaneously on **N** of these channels with the frequencies f1, f2,..fN. An advantage of this method is that it allows to avoid the channels corresponding to the forbidden frequencies and therefor to increase the operating signal level.

The coding method is to be chosen according the intended functions. An important point to consider is the simultaneous emission of different applications eg. Commands and Internet or Telephone, downwards or upwards. A certain number of channels is allocated to each application .

5.6 Guidance for the assessment of the signal level

The different factors described above which have to be considered makes it somewhat complex to asses the actual characteristics of a PLC system. The following example may serve as guidance taking into account the uncertainty about the applied factors.
It is assumed a system with an operational bandwidth of 1MHz (2 Mbits/s), OFMD modulation (which offers a good protection against noise pulses) and average values of the considered factors .

The following way may be applied:
- Broad band disturbance level
  with B = 100 kHz ≈ 35 dBμ V
  → with B = 1 MHz: ca 45 dBμ V
- Safety margin: assumed 10dB
- Signal attenuation on the Power Cable: 60 dB
- Injected voltage = 45+10+60 =115 dBμ V / 0,56 V
- Coupling factor: -45 dB
- Radiated field: 115 dB V – 45 dB = 70 dBμ V/m
  →30 mV/m

Another calculation method could be based on the power density spectrum PDS.

Some remarks:

-The signal level at and around the emission point exceeds the limits of CISPR 22 (max 60 dB μV)
- The radiate field exceeds the allowed German and British limits for the radiated field (max outside the chimneys 50 dB μV/m).
- Above example is not acceptable. The field condition of NB 30could be met with a signal of 20 dB less. Several manufacturers claim that they can fulfil this condition. However the requirement of CISPR "" are very severe and the question is raised if for PLC relaxed limits should not be considered [3]

6 Measurement techniques

Two cases of measurement should be considered :
-measurement in situ of an operating system. Particularly to be measured is the radiated field. As mentioned above it is recommended to measure the magnetic field and to calculate from it the electric field. The measurement equipment is the one described in CISPR 16 with a loop of 60 cm.
-measurement for the purpose of certification. A relevant standard has not yet be developed. A difficulty comes from the fact that the load of a PLC emitter in the network is very variable (chapter 2). For certification purposes definite conditions, particularly a definite load, shall be defined . It is considered to use the 50Ω/50μH artificial network.

In all cases the spectrum analyser has to be according CISPR 16-1. Two characteristics have to be chosen:
-the bandwidth according to the modulation characteristics
-peak, quasi peak, average value? Peak value seems appropriate with regard to the immunity of the coding

7. PLC at beginning of 2001

An intensive development work on PLC is carried out presently and several systems seem to be operational. Trial installations have already been put in service . In Europe, for Utilities, the use of their LV network for Internet and as "last mile" for the telephone could be the most interesting applications. A wide application is hoped plication in the USA. It is not easy to predict today what can be the future of PLC taking into consideration the competition of other channels: TV cables, radio links,.. and the economic constraints, In countries where these techniques are not yet well developed PLC may be successful. Anyway PLC is a very attractive technique.
The technical and standardisation work must be completed. It would be useful to have e.g. :
- as important preliminary: in all the involved bodies a unique and coherent system of units
- reference values for the voltage attenuation
- reference values for the conducted noise
- reference values for the coupling factors
- refer all the proposals for radiation limits to the same conditions and units
- specify the measurement technique (important !)
-certification (particularly in CENELEC)

Other aspects like modulation methods, coding, applications, etc,... belong rather to the design of the particular system or equipment .

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MEASUREMENT OF DISTURBANCES DUE TO THE USE OF LOW VOLTAGE POWER NETWORKS FOR DATA TRANSMISSION. PROCEDURES AND RESULTS

Abstract. The use of the low voltage power network for data transmission can produce radiated disturbances. A measurement procedure which attempts to take into account the large variety of existing inhouse configurations has been proposed by the University of Karlsruhe. The paper describes the measurement procedure and presents experimental results on different sites. It also shows that the commonly-adopted assumption of a plane wave to calculate the electric field from magnetic field measurements can lead to significant errors, especially for the determination of the indoor electric field radiation. However, these errors are within the uncertainty resulting from the large variety of indoor electrical network configurations.

I. 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 2 – 3 years, feasibility studies have been performed in various countries to check the possibility of using the low voltage distribution network to provide data transmission services to individual customers at frequencies up to 30 MHz [1,2]. This application is particularly interesting for power utilities allowing them to enter in this way into the telecommunication market.

The major benefits of power line communication (PLC) systems are:

- availability of information technology at all plugs in a house;
- creation of home LANs with no additional wires;
- possibilities of connection to internet of remote areas non yet linked to the phone network;
- an increased competition among different providers of information and as a consequence lower prices on the market.

However, PLC transmission systems in the frequency band extending from 1 to 30 MHz will present various and quite complex EMC problems (see e.g. [3-7]). The main problem would probably be the emission of electromagnetic noise which can interfere with public and amateur radio.

II. Definition of a measurement method

In order to take into account the large variety of transmission lines and cables along the streets and the different in-house circuits, a transfer function named also “coupling factor” has been defined as [8]

$$\kappa_E(f,\vec{p}) = \frac{\left|\vec{E}(f,\vec{p})\right|}{U(f)} \quad \text{(1/m)} \qquad (1)$$

where $\vec{E}(f,\vec{p})$ is the measured electric field at a given position $\vec{p}$ and $U(f)$ is a harmonic voltage of frequency f injected in the network for measuremnt purposes.

This “coupling factor” must be first determined for each location (outdoor street or indoor room) where the field level should be known. After the determination of this “coupling factor”, the radiated field from any PLC system can be easily evaluated.

A similar definition for the magnetic field coupling factor can be given as

$$k_H(f,\vec{p}) = \frac{\left|\vec{H}(f,\vec{p})\right|}{U(f)} \quad \text{(A/Vm)} \qquad (2)$$

Both electric and magnetic coupling factors can be also expressed in dB as

$$k_{EdB}(f,\vec{p}) = 20\log\left(\left|\frac{\vec{E}(f,\vec{p})}{U(f)}\right|\right) \quad (\mathrm{dB}_{1/\mathrm{m}}) \tag{3}$$

$$k_{HdB}(f,\vec{p}) = 20\log\left(\left|\frac{\vec{H}(f,\vec{p})}{U(f)}\right|\right) \quad (\mathrm{dB}_{\mathrm{A/Vm}}) \tag{4}$$

The use of the magnetic coupling factor instead of the electric one has a first very important advantage due to the fact that the magnetic field is easier to be measured than the electric field. Besides the difficulty in measuring the electric field and its sensitivity to the environment, there is today no tri-dimensional electric field sensor on the market enough sensitive for the levels with which one is faced in this technique. The sensitivity level which is needed can be estimated from the curve presented in Fig. 1. This figure shows the German PLC limit proposal called NB30 combined with a proposal for exceptions at certain frequencies [9]. The result is the so-called chimney curve which is today in discussion in the standardization bodies.

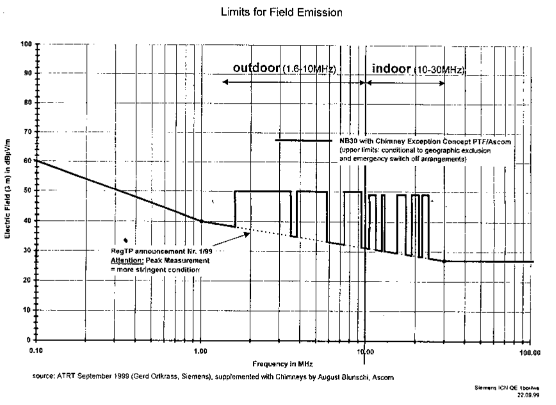

Fig. 1 – The chimney limit curve.

It can be seen that the lower limit for the radiated field is about 40 dBμV/m, corresponding to 100 μV/m.

The experimental determination of the coupling factor is illustrated in Fig. 2.

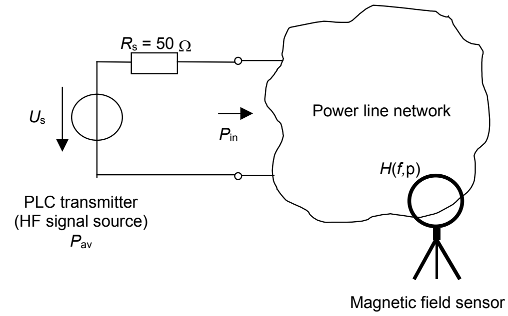

Fig. 2 – Experimental determination of magnetic coupling factor [8].

The complete diagram of the measurement set up is shown in Fig. 3. This set up has the following devices [8]:

- a CW-generator. To inject a signal any common waveform generator covering frequencies from 9 kHz to 30 MHz can be used. The generator should not inject any spurious CW-signals via its mains into the power line network.
- An RF-amplifier with the same range from 9 kHz to 30 MHz as the generator, in order to ensure a good S/N-ratio.
- A directional coupler if power measurements are performed. The coupler permits the measurement of both the injected power into the network and of the reflected power due to network impedance mismatch.
- A high impedance voltage probe if the injected voltage is measured. The voltage probe should be designed as a differential probe to avoid coupling from differential to common mode.
- A coupling unit which transforms the asymmetric voltage at its input into a symmetric voltage at the output. The better this transformation is achieved, the lower will be the common mode current injected in the mains. This coupling unit will be used for the real signal injection and therefore must be present also when the measurements are performed.
- A measurement receiver with its input ports connected to the antenna and the voltage probe and its output ports to the coupling unit. The measurement receiver can be a spectrum analyzer if precautions are taken to avoid the overloading of the

mixer which can result in a non-linear behavior.

- An antenna connected to the spectrum analyzer. For magnetic field measurements a loop antenna with a diameter of 60 cm is recommended. Electric field measurements will be discussed later.

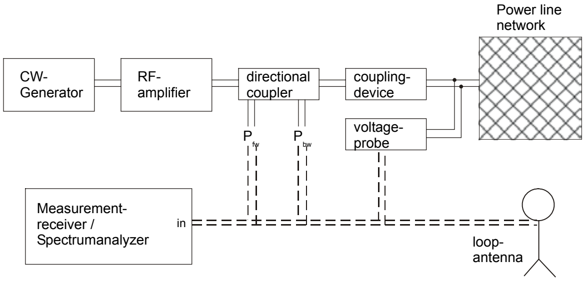

Fig. 3 – Set up for the coupling factor measurement.

III. Determination of the electric field coupling factor

A monopole antenna with the required sensitivity can be used to measure the vertical component of the electric field.

A common procedure is to transform magnetic field into electric field by multiplication with the wave impedance (plane wave assumption). If this approach is correct for distant fields, it cannot be applied to predict the indoor E-field radiated by PLC systems .

The computed ratio E/H as a function of the distance from a given PLC network is shown in Fig. 4 [7].

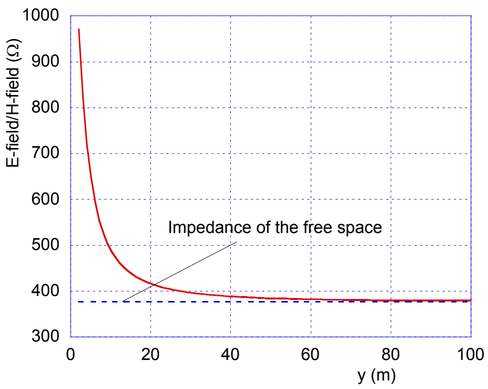

Fig. 4 - Variation of the ratio E/H as a function of distance from the PLC network (f = 30 MHz).

It can be seen that for distances less than 10 m which is a maximum for a room in a house, the ratio E/H impedance value is much larger than the value of the free space impedance.

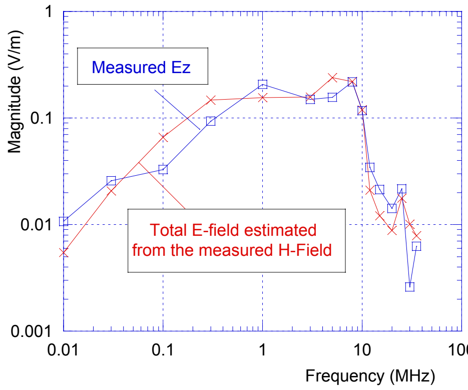

Fig. 5 – Comparison between the vertical electric field component measured directly with a dipole antenna and the total electric field determined by using the measured magnetic field and assuming a plane wave.

The incorrect results which can be obtained by using the free space impedance can also be seen from Fig. 5 where the measured vertical electric field component is shown to be larger, at some frequencies, than the total electric field computed from the magnetic field using the plane wave assumption [7].

IV. Results

Magnetic field measurements in various environments have been performed by the Universities of Dortmund and Karlsruhe and by the Swiss Federal Institute of Technology of Lausanne (SFIT). An example of the measured magnetic field components in an indoor environment and of the total field computed from these components is presented in Fig. 6.

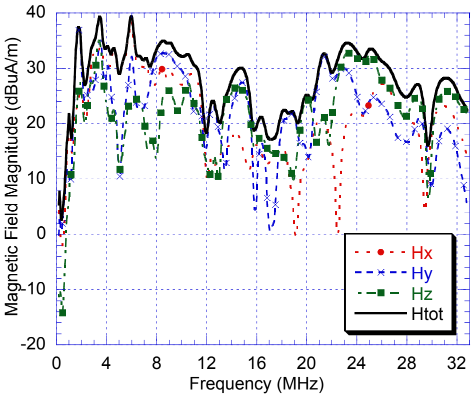

Fig. 6 – Example of measured magnetic field

Putting together a large number of coupling factors measured in various environments and for various configurations results in a family of curves [9] (Fig. 7). Here t_{80} represents the CISPR 22 limit, which says that at least 80% of the measured fields will be lower than this limit.

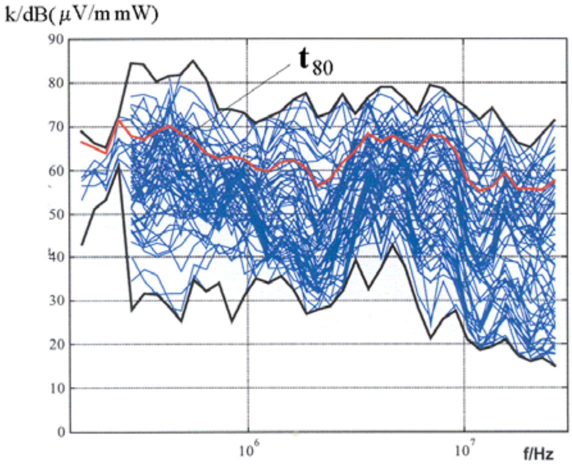

Fig. 7 – Family of curves of the coupling factor as a function of frequency resulting from in-house measurements for different configurations. t_{80} represents the CISPR 22 80% limit.

The variation between the maximum and the minimum of this family is of the order of 50 dB. If the 80% probability is taken into account, then the values are situated in the range of 30 dB. Due to the large variety of configurations in practical situations in which a PLC can be installed, an important variation of coupling factors cannot be avoided. This large range has to be compared to the error in the electric field calculation resulting from the assumption of the plane wave which is of the order of a factor 2 to 3, i.e. 6-10 dB. In this case, it is clear that for averaged estimations of the emission, the use of the plane wave approximation can be considered as reasonable.

V. Estimation of the radiated field level

An example of the magnitude of radiated field can be obtained using the following data. Assuming an injected signal with a power spectral density of – 40 dBm/Hz, and using a typical bandwidth of 9 kHz (corresponding to 10log(9kHz) = 39.54 dBHz), the injected power is therefore

$$P = -40 \text{ dBm/Hz} + 39.54 \text{ dBHz} = -0.46 \text{ dBm}$$

Using an average coupling factor (fig. 7) of $k_E = 50\ \text{dB}_{\mu V/m}$, one obtains

$$E = P + k = -0.46 \text{ dBm} + 50 \text{ dB}\mu\text{V/m} = 49.54\ \text{dB}_{\mu V/m}$$

Comparing this value with the chimney curve limits, it can be seen that the calculated value exceeds for the whole frequency spectrum chosen for the PLC (1 to 30 MHz) the upper limit proposed for the chimneys. If no chimneys will be allowed, this radiated fields exceed by about 20 dB the limit proposed by the NB30 curve.

VI. Conclusion

The difficulties for estimating the field radiated by the low voltage network when used for data transmission (PLC systems) have been analyzed. The difficulty results from the large variety of configurations occurring in practice. This means that only average radiated field values can be estimated and that there will always be a danger to exceed the limits. Therefore a pragmatic approach would be that the regulating authorities should act only if there is a complaint for malfunction of some devices or disturbances in a particular environment.

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POWERLINE COMMUNICATION SYSTEMS NORMATIVE AND REGULATORY ASPECTS FOR THEIR APPLICATION

Abstract Using the electricity supply network for information transmission, powerline communication (PLC) technology is succee-ding powerline carrier systems operating via the high voltage grid as well as ripple control systems, by offering some valuable new technical features as well as the possibility to achieve new telecommunication services, those being of particular interest in an increasingly competitive environment.

While narrow-band PLC systems have been standardized since the late eighties and put into operation in a lot of cases, for broadband PLC systems questions still left open concerning possible disturbing effects on other systems, like radio services as well as on other electrical equipment, and due to that a lack of a normative and regulatory frame may build a threshold for the market entry.

1. Scenario of application

Four fields of application could be covered by PLC technology:

- **outdoor**, i.e. in the public supply network area: automatization, monitoring, remote measurement functions, operational telephony; that by using the existing distribution network, without additional installation of lines.
- **indoor**, i.e. within the customer premises: Control and monitoring including alert functions, internal communication systems (so-called "domotic"), easy networking of data processing equipment; that by using the existing customer's installation without additional installation of lines or application of radio equipment.
- „**cross-border**“, i.e. by connecting the in-door and outdoor PLC areas: Services for the customer close to the power supply, e.g.

✓ monitoring of the state of operation of systems, with appropriate re-action

✓ remote control of equipment (like electrical heating or water boilers) and of tariffs (recently achieved by ripple control)

✓ remote meter reading – today already achieved by some utilities related to customers with special tariffs --, measurement of load profiles as well as monitoring of the loads in customers' systems respectively in the distribution network, related data getting transmitted via PLC to the utility's Control Centre and there processed in the course of an optimized load management.

- **Provision of public telecom services**, by connecting the outdoor PLC system to a telecom backbone: e.g. high speed internet access, public telephony, video on demand.

2. Application conditions

2.1. General

As key criteria for a successful market entry of PLT systems, those competing with other and future communication media, there may be recognized:

• **economic feasibility** – i.e. information transmission over line distances in the range of some hundred meters,

technically

– meeting electromagnetic compatibility (EMC) requirements and therefrom resulting limitation of levels for signal injection

– ensuring a sufficiently high gross data rate, by that ensuring provision of the single customer with services as considered with appropriate speed as well as with a bit error rate (BER) being appro-priate for the service quality,

commercially

– possibility to finance the application of such systems by the services provided on their base, that considering a given **competitiveness** with alternative systems.

- the **successful performance of related field trials** and the application of the obtained recognitions at optimization of technical system development.
- the **availability of a normative and regulatory framework, as a base for invest-ment security**. There seems to be given a certain time window, determined by the development of other technologies, finally future fibre connections for customers. It is told that this window may be shut in 2002.

2.2. Normative and regulatory conditions

2.2.1. EMC as the key issue

While the signals being transmitted by a PLC system represent the intentional signal within the system, for other equipment connected to the related supply network these signals appear as components of the supply voltage besides the primary 50-Hz-supply.

In narrow-band PLC systems, the signal essentially propagates via the conducted path. In broadband PLC systems, using higher frequencies, with increasing frequency the signal trans-mission results in an increasing radiation of un-intentional field-strength; the resulting wave propagates via ground, space and sky wave. The cumulative effect of the field-strengths stemming from different supply networks is to be considered. That related to the field-strengths caused by all PLT users being active in different supply networks at the same time.

Due to the sky-wave – getting reflected at the Ionosphere depending on seasonal, daytime and weather conditions – the effect of the cumu-lated field-strength stemming from one major area is to be considered in far distant areas (distances of more than 1000 km).

Unseen the regulatory situation in different countries, consideration is needed of the fact, that the radiation from HBR systems may cause disturbances to radio systems like those of the air surveillance, radio astronomy, amateur radio, broadcast or military area; that also regarding the higher signal injection levels needed because of the attenuation dependant on parameters like frequency, daytime, load situation and location. For Europe an order of magnitude of 20.000 radio services is reported.

Due to

- the wide-scale EMC issue concerning radio services,
- the given obligation for standardization to perform work in a European context,

setting of national regulation for a regular application of HBR-PLC systems by the responsible authorities is determined by meeting the requirements of EMC Directive 89/ 336/EEC and following amendments respec-tively its national transposition and the results of related European and international standardization.

2.2.2. Standardizational and regulatory responsibilities

Work on related standards and regulations is under way on several levels worldwide.

Normative aspects are dealt with in

- the European Committee for Electrtechnical Standardization (CENELEC)
- the European Telecommunications Standardization Institute (ETSI)

- the International Special Committee on Radio Interference (CISPR).

Issues like **frequency application** (and therefore the co-existence between PLC technology and radio services) are (mainly) dealt with in

- the European Conference of Postal and Telecommunications Administrations (CEPT) and its European Radiocommu-nications Office (ERO) and
- the International Telecommunication Union (ITU).

Furthermore, related work of the Institute of Electrical and Electronic Engineers, USA, (IEEE) is to be mentioned, where a document for narrow-band systems (frequency range for USA: 50 kHz – 450 kHz) has been worked out

As has been stated by CEPT in the meantime, no frequency allocation for HBR-PLC systems can be considered. That referring to the restriction of frequency allocations only to radio systems in general (to what such PLC systems – their radiation representing a disturbance relevant subsidiary phenomenon of system operation – cannot be considered to belong).

Additionally, frequency authorities draw attention to the needed protection of existing radio services as well as of the unrestricted use of the frequency ressource by radio applications as to be expected in future.

2.2.3. Standardization, available documents

Standardization concerning **narrow-band PLC systems**, which are mainly designed for utilities' operational purposes (like e.g. remote meter reading) on the one side or consumer applications within customer premises, has been performed since the late eighties. Related standards – comprising such ones dealing with frequency use, maximum signal levels, immunity, filters and equipment impedance – are available or at the finalization stage (EN 50065 series).

Compared to that, the normative development for **broadband**-PLC systems is just short after its start, which has taken short after its start, which has taken place in 1999.

Concerning HBR-PLC systems, CENELEC and ETSI are working in one Working Group each (ETSI: EP PLT, CENELEC: SC 205A WG10) as well as in a Joint WG, the latter one also practising some cooperation with CEPT and CISPR but which is deemed necessary to be intensified.

Up until now the following **product specific documents** have been worked out:

- a so-called "Co-existence"-document TS 101 867:2000-11 from ETSI, dealing with the co-existence between in-house and outdoor systems, primarily by dividing the overall frequency range (1,6 MHz - 30 MHz) into two parts, by a so-called "split-frequency", and adjoining the lower part to outdoor, the higher part to indoor systems.
- a similar CENELEC prEN 59013, being identical with the before-mentioned ETSI TS, differing only in the value for the split frequency – giving a value of 13,5 MHz instead of 10 MHz in the ETSI TS.

Discussions on this split frequency highlighted the thorough commercial oppositions between manufacturers of outdoor and inhouse equipment, an opposition which up until now hindered a positive vote on the prEN.

In the meantime, for a second generation of PLT-equipment, a solution allowing the use of the entire frequency range in case of no PLT operation in one of the two part bands is under consideration.

- a so-called "PSD"-document TS 101 896: 2001-02 from ETSI, proposing limits for the power spectrum density,
- a so-called "Radiation"-document from CENELEC proposing comparable ***limits for the*** level of the ***injected signal power*** (dB(mW/Hz)) and for the radiated ***field strength*** in a distance of ***10 m*** in an Informative Annex, the latter being related to the signal power via a coupling factor, for the latter only empiricly obtained ranges of values are available for calculations.

Furthermore two documents – in the European context to be recognized as „regional“ ones -- may be mentioned:

- the German “Nutzungsbestimmung” NB 30, from the Regulierungsbehörde für Tele-kommunikation und Post (RegTP), after having been discussed since 1999 having got endorsed by the Deutsche Bundesrat on 30/03/2001. This paper has not been notified to the European Commission. According to this paper, frequencies in the range from 9 kHz to 3 GHz in and along lines should be freely applicable for telecommunication systems if some conditions are met:
  - spare of different frequency ranges being used by security related radio services
  - meeting defined ***limits for the*** peak values of the radiated ***field strength*** in a distance of ***3 m***
  - no given protection against disturbances from intentional radio systems.
- The British Radiocommunications Agency specified ***limits for the field strength*** radiated from telecommunications systems in the frequency range 150 kHz - 300 MHz, in a distance of ***1 m*** (150 kHz to 1,6 MJz) or ***3 m*** (1,6 MHz to 30 MHz) which are some 20 dB below the limits of NB 30.

The only existing, harmonized standard which is told by authorities to may be used for the evaluation of disturbances from PLC systems is EN 55022. For the frequency range 150 kHz – 30 MHz, this standard, based on CISPR 22, gives ***limits for the conducted signal voltage*** (dB(μV)). If these limits, not being immedia-tely convertible into limits for the field strength (coupling factor, ranges !) and there-fore not being easily comparable with the limits of NB 30, would be applied to HBR-PLC systems, their operational radius would be reduced to a fraction of 300 m, this value being considered as a measure for economical operation of HBR-PLC systems, without application of repeaters. At present CISPR is drafting an amendment to CISPR 22 stating that PLC systems would fall into the Scope of CISPR 22.

3. Field trials

Concerning **narrow-band** PLC system a remarkable number of field trials has been performed. Several systems, e.g. that within the ENEL in several Italian cities, are in regular service since some time or are getting enlarged at present.

Recently, also field trials concerning **broadband** PLC systems are performed in several countries or envisaged to get started.

The results obtained during these field trials lead to the following cognitions:

- satisfactory functionality at high speed internet access and telephony,
- different given needs/possibilities for opti-mization; e.g. by optimization of the software and modification to the application of part frequency bands an improvement could be reached for the data rate, from 1,8 Mbit/s to about 3 Mbit/s.
- limitation of the field strength to a value according to NB 30 may lead to a reduction of the feasible distance for the „last mile“ by about a half, limitation according to EN 55022, Class B, (residential area) may lead to increasing unprofitableness.
- high customer interest in the offer of related services, in particular concerning the relatively high data rate for internet access as well concerning the competitive tariffs, the increase of competition being also in the interest of the European Commission.

4. Questions left open, possible solutions

Contrary to narrow-band PLC, the normative and regulatory development for HBR-PLC systems is just under way and a number of questions are left open:

- a well-balanced solution for the frequency use, ensuring co-existence with radio services and other electrical equipment.
- the frequency management between dif-

ferent PLC systems concerning network relations and distances relevant for possible mutual disturbance effects, that considering

- different system technologies
- clarification about who would care for an appropriate frequency management – in case of no obligation for licensing
- questions of the use of supply networks in a liberalized environment.

o to cope with the „raw" transmission channel – by appropriate adaptive modu-lation --, which due to the load shows varying impedance, the variation showing some dynamic due to the relatively high operational frequencies.

o co-existence of a PLC system with the operation of the supply network.

o economic operability – besides the basically given and in field trials proven – technical functionality.

Regarding

- what has been recognized during the ongoing standardization work, including the statement from frequency authorities that no frequency bands could be allocated for PLC systems
- the results from field trials, according to which an economic operation of HBR-PLC systems with signal levels meeting the limits of EN 55022, Class B, is to be called into doubt
- the results from different measurements, like e.g. at the University of Dortmund with about 200 CE-marked PCs and workstations showing cumulated field strength values above NB 30 but without any recognized disturbance effect, therefore calling into doubt the justification for the stringent limits of EN 55022 in general and their application to HBR-PLC systems
- a comparison with other fields of normative limitation of field strengths, e.g. with that for electric trains (prEN 50121)

a possible way of solution could be assumed by normative specification of PLC-specific limits for the radiated field strength, those

- appropriately considering the coupling factor, based on the given situation concerning network impedance and wave propagation
- getting set higher than equivalent to the limits for the injected signal voltage according to EN 55022, which recently is applied as a substitute, by considering a sufficient protection of radio services and in consen-sus with CISPR.

5. Summary

From the present point of view, the application of narrow-band PLC systems – duplex, contrary to the mainly monodirectional ripple control technology – in any case seems to have a market in future

- for utilities' operational purposes
- for easy and cheap achievement of "domotic" and networking solutions within the customer premises
- for offering of services close to the electricity supply; in the latter case also as a means of customer care.

The reason why such systems haven't reached broader application up until now may be explained by the situation that since the near past electricty utilities as potential appliers may intend to wait for mature HBR-PLC systems with which such tasks could be covered as well.

HBR-PLC technology appears as a means of high interest for realization of telecommuni-cation services, „classical" ones like internet access, telephony and data transmission, as an alternative to other access technologies, as well as of additional services close to the electricity supply.

In less-industrialized countries, with a lower degree of provision by basic telecommuni-cation services like tele-phony, PLC technology could find its market by offering a means for easy achievement of such basic telecommu-nication; that due to a given coverage of about 90 % con-cerning electricity supply in those countries.

The essential prerequisite for a successful market entry of HBR-PLC systems, for which mass equipment is announ-ced to become available on from mid 2001, is the avail-ability of an appropriate normative and regulatory frame as soon as possible.

With view to the given customers' interest in the use PLC technology and to the feasible palette of services – besides the commercial interests of manufacturers and electricity utilities – from the PLC technology's point of view it will be a task of existential importance for the standardization bodies as well as for the responsible authorities to find solutions to the questions left open and to find settings in cooperation with those responsible for the protection of radio services, which ensure a regular application of PLC systems by giving investment security.

To achieve that goal, the primary task will be to obtain first stable standards which

- inevitably will force manufacturers to adapt their existing products to a certain degree, however, but
- will give clarity for the basics of this technology and its regular application.

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