Practical Papers, Articles and Application Notes

Flavio Canavero, Technical Editor

The first article of this issue is entitled "The Difficulty of Reaching Consensus in the EMC Standardization for Power Line Communication" by Mariano Giunta and Michel Ianoz, members of IEC Standard Committees. Broadband power line communication is a technology operational for over a decade, but its EMC regulation is still a controversial issue. In this paper, the authors provide an overview of the standardization process for this technology. They also discuss the regulation in different countries and present new applications potentially boosting this technology in the future. The second paper belongs to the "Education Corner" thread that I started a few issues ago. It represents the first of a two-part tutorial on EMC in power systems. In this paper, entitled "EMI Issues in Modern Power Electronic Systems," the author Firuz Zare (Queensland University of Technology, Brisbane, Australia) presents the design of power electronic systems in light of the EMC constraints, and addresses the great challenge of matching efficiency with quality (*i.e.*, low EMI noise) in modern power electronic systems. In conclusion, I encourage (as always) all readers to actively participate in this column, either by submitting manuscripts they deem appropriate, or by nominating other authors having something exciting to share with the EMC community. I will follow all suggestions and with the help of independent reviewers, I sincerely hope to be able to provide a great variety of enjoyable and instructive papers. Please communicate with me, preferably by email at canavero@ieee.org.

The Difficulty of Reaching Consensus in the EMC Standardization for Power Line Communication

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Abstract—The new Power Line Communication (PLC) technology was introduced over 10 years ago. Three types of standards have to be developed for PLC, namely product, network and coexistence standards. In spite of all the efforts dedicated to this task, very little progress has been achieved. This paper will present the state of art pertaining to the three types of standards. It will also discuss the situation on the regulatory side in different countries and present new applications which could boost this technology in the future.

1. Introduction

Distribution power lines have been used for a long time to transmit specific information pertaining to the network operation or to various services which electric utilities are offering to their customers. The range of frequencies used for this service was from a few hundred Hz up to 150 kHz, where the public radio frequency band begins.

By the end of the 20th century, this technology was applied for data transmission and eventually also telephonic links to individual customers at frequencies up to 30 MHz [1, 2] (fig. 1). This application is particularly interesting for power utilities which can enter in this way the telecommunication market.

The big advantages of using PLC are:

- Use of the existing distribution network;
- No additional investments for ADSL or optical fibers
- Easy distribution of new services inside the house (e.g. IPTV)

However, this transmission mode in the frequency band extending from 1 to 30 MHz presents various and quite complex EMC problems. The main problem is the emission of electromagnetic noise which can interfere with public radio, fire alarms, military communications or radio amateur links, which all are using the same frequency spectrum from 1 to 30 MHz.

In order to protect these services, limits should be fixed for the fields radiated by the PLC devices and networks by developing appropriate standards.

Unfortunately, the problem of establishing these limits has been one of the most controversial subjects from the beginning of the introduction of this technique.

2. EMC Emission Problems

The power distribution network at the level of a town district is used to transmit information by sending it from a so-called backbone station through cables running along the streets which then enter individual houses, administrative buildings or industries.

EMC emission problems [3] due to the use of the LV power network for information transmission are at three different levels:
- Indoor level;
- Outdoor level;
- General environment level.

2.1 Indoor Level

When signals at frequencies up to 30 MHz are transmitted through the low voltage distribution network, indoor disturbances can occur due to the possible interference of the electromagnetic field radiated by the network with various installations: radio receivers, video equipment, CD players and others.

The difficulties to determine the level of such disturbances are connected to:
- The complicated and very big variety of the possible arrangements of the LV network in a house;
- The small dimensions of the rooms which does not permit performing measurements at distances from the disturbance source larger than about 1 m. The consequence is that these measurements will be performed in a strongly non-uniform field.

This means that for modeling the LV circuit in an individual house or public building (administrative or industry) in order to calculate radiation, codes like NEC can be used, but for this task one needs computers with large memory as well as a large number of calculations to include a big variety of configurations and obtain a statistical result.

For the experimental part, due to the high non-uniformity of the field in the small rooms of the houses, a field mapping over the room surface will be needed. As for the calculations, due to the big variety of configurations, in order to have reliable results, a large number of measurements will be needed.

The first published results in this direction [2] show that the CISPR 22 limit for conducted emissions is not respected for a PLT (Power Line Technology) modem connected on the LV network (fig. 3). Even if this result should be taken with precaution because it shows the peak value, while the limit is fixed for the quasi-peak, it gives an indication that EMC problems might arise when this power line technology (PLT) or power line communication (PLC) are used inside a house.

2.2 Outdoor Level

It can be assumed that at some moments of the day, due to the simultaneous input coming from a large number of individual connections, the total traffic flowing in the outdoor cables along a street can be quite high.

This can mean that these cables can radiate a significant field in the environment and eventually in the vertical direction, where there is no barrier for the field; this disturbance can reach flying objects and interfere with their electronics. For the moment, this is a non-verified assumption, but it represents a potential danger which must be checked.

2.3 General Environment Level

In a very populated town, the addition of signals in many outdoor cables can even represent a kind of very large antenna

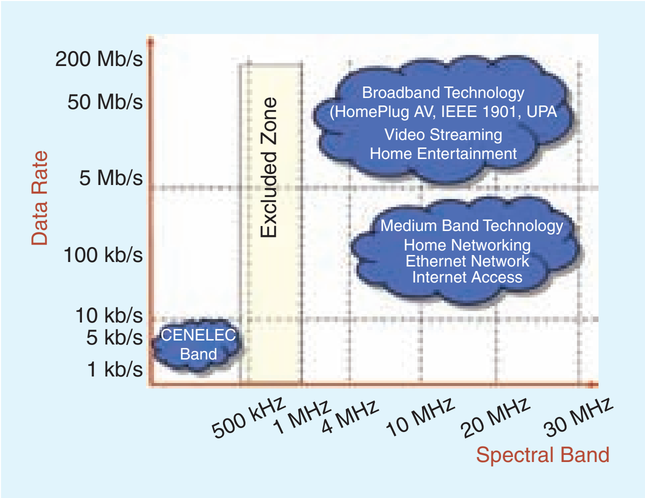

Fig. 1. Power line communication applications.

which will eventually send such noise signals into the ionosphere. Of course, this is also for the moment a speculation which possible occurrence must be checked by modeling or experiments.

3. Standardization Aspects

Three types of PLC standards must be developed:
- A product standard, for specific PLC products such as modems permitting the connection to the mains (230 V distribution network).
- A general communication network standard, defining the permitted radiation limits.
- Coexistence standards, permitting for instance the coexistence between different PLC technologies in the same network or between apparatus from different vendors that use the same technology.

The CISPR product committee CISPR/I has defined in a document CISPR/I/26/DC the need for a corresponding product standard. Working Group 3 was charged to introduce the needed changes in CISPR22 [4].

The European Commission published on August 7, 2001 a "Standardization Mandate Addressed to CEN, CENELEC and ETSI concerning Electromagnetic Compatibility (EMC) in Telecommunication Networks" (Mandate 313) [5]. Its scope is to develop EMC harmonized standards (for emission and immunity) for telecommunication networks.

However, since 2001, little progress has been achieved pertaining to the development of PLC standards.

3.1 Product Standard

A first idea was to extend the concept of Longitudinal Conversion Loss (LCL) specific for symmetric telecommunication pairs of wire to the non symmetric power network.

However, measurements performed in various power networks have given a large spread of LCL values (fig. 2) [6].

It was not possible to arrive to a consensus for the concept for the calculation of a voltage limit at the ports of the equipment connected to the network, based on the LCL value.

At the beginning 2005, a New Work Item Proposal (NWIP) was accepted by the National Committees [7]. The title was

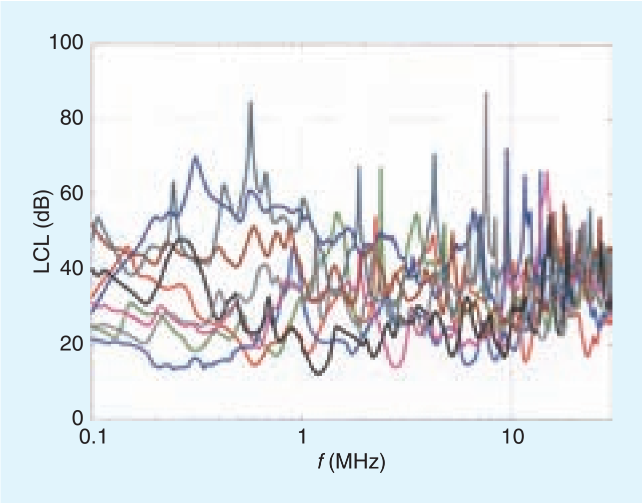

Fig. 2. LCL values measured at various power network sockets by the University of Dortmund.

"Amendment to CISPR 22: Limits and method of measurement of broadband telecommunication equipment over power lines," and the scope of the document defined as follows: "To prepare an amendment to CISPR 22 that specifies the limits and method of measurement of radio disturbance characteristics of broadband telecommunication equipment using the power lines for transmission of the signal in the frequency range 1 to 30 MHz."

Together with this NWIP, the project team CISPR/I/PT PLT was set up. Its initial work was focused on the following:

- Describe the typical electricity installations where it is intended to connect PLC equipment;
- Identify the potentially disturbed services/equipment for each typical section of electricity installations described above;
- Assess the level of protection currently provided by CISPR 22 for each equipment/service;
- Set radiated and conducted limits for emissions of each typical section of electricity installation when PLC is operating.

Two documents were issued in 2006:

1. CISPR/I/186/DC [8] corresponds to task 1: "describe the typical electricity installations where it is intended to connect PLC equipment."

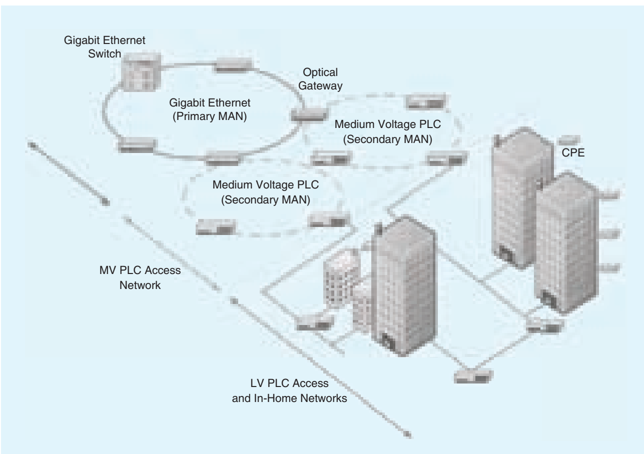

Fig. 3. Example of a typical PLT topology.

2. CISPR/I/211/DC [9] corresponds to task 2: "for each typical section of electricity installations described in Task 1, identify the potentially disturbed services/equipment."

The first document (CISPR/I/186/DC) was divided into two main chapters:

- Classification of locations where PLC equipment are connected;
- Description of elements that constitute electrical network topologies and PLC network architectures (fig. 3).

A certain number of comments have been received from the National Committees (NC), for example [10]:

- The UK NC considers that the electrical networks are very different from one country to another. These differences must be taken into account;
- The US NC advised that EMC requirements common to all types of PLC networks, such as limits and tests, must be defined.

Concerning the second document CISPR/I/211/DC, 21 physical elements to which the PLC signal can be coupled were identified as, for example, overhead or buried MV or LV cables.

For each class of installation of PLC equipment, a description of coupling paths was presented.

The most probable risk of disturbance was identified. For instance, for a transformer substation of house-type in surface, used as PLC backbone, there is a probability of interference with two types of equipment:

- Outdoor radio services with a coupling path of 30 m in the air;
- Indoor radio devices with a coupling path of 30 m in the air plus a wall.

Following these first two CDs, in February 2008 a new document CISPR/I/257/CD [11] was issued dealing with measurement methods and emission limits for PLT connected to the mains at the customer premises. This CD is a result of all studies and contributions made in CISPR/I/PT PLT. The test method proposed is based on the use of a T-ISN with a 25 Ω common mode impedance. This value was selected to be equal to common mode impedance of the AMN (V-network) used to measure the unsymmetrical voltage generated by the EUT. The compromise LCL value of the T-ISN of 24 dB was chosen considering more than 600 LCL measurements from six different countries. The LCL of the T-ISN was also determined in such a way that two sources, a symmetrical one measured using the T-ISN and an asymmetrical one measured using an AMN cause comparable interference on a dummy radio. The test set-up with the T-ISN is similar to the present CISPR 22 test set-up used for the telecommunication ports. From 1.605 MHz to 30 MHz, the PLT ports are tested twice: T-ISN is used when the telecommunication function is active while the AMN is used for conformance testing when the telecommunication function is inactive. From 150 kHz to 1.605 MHz, the PLT ports are measured using only the AMN. The limits proposed in this CD are the voltage limits applied to the mains ports according to CISPR 22 while the current limits are derived for use with this new T-ISN considering the conversion factor 20 log10(25 Ω) = 28 dB. The answer of the National Committees reflected a variety of potential approaches that were reviewed in the CISPR/I/PT PLT Dallas meeting in June 2008 and as result of the review, a second CD is in preparation. This second CD will include mitigation techniques of notching/power control based on the result of the document CISPR/I/269/

DC [12]. During the Osaka meeting that was held in October 2008, it was concluded that some items regarding the level of protection need to be reconsidered. At the moment, the in-house application takes precedence over access application that will be considered later.

3.2 Network Standard

After the mandate issued by the European Commission in 2001, a Joint Working Group ETSI/CENELEC was created.

Different limits have been proposed by various countries (Germany, UK, and Norway) and entities (CENELEC, FCC, and BBC) (fig. 4).

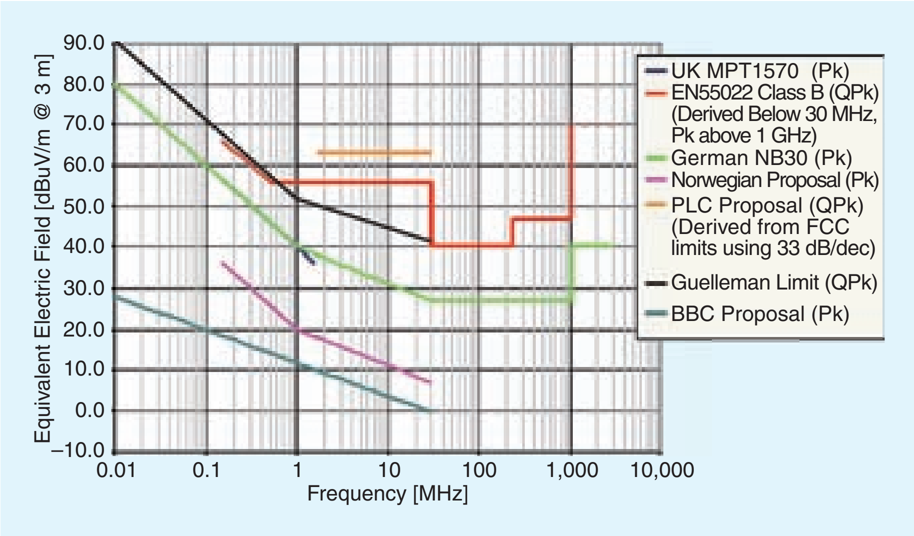

Fig. 4. Electric field limits proposed by different regulatory bodies for PLC emission.

After five years of meetings and several documents issued and submitted to the National Committees, no consensus could be reached.

As a consequence, at the meeting of 21–22 February 2006, the JWG decided to freeze the work [13]. Recently the activities of the joint working group CENELEC/ETSI on EMC of Conducted Transmission Networks were resumed and three new draft standards were prepared:

pr EN 50529-1 EMC network standards Part 1: Wire-line telecommunications networks using telephone wires;

pr EN 50529-2 EMC network standards Part 2: Wire-line telecommunications networks using coaxial cables;

pr EN 50529-3 EMC network standards Part 3: Wire-line telecommunications networks using power lines.

The first and second draft standards pr EN 50521-1 and EN 50521-2 have been sent to public inquiry while the draft EN 50521-3, related to PLT, was sent to the National Committees for informal comments.

Concerning the network standard, it should be noted that ITU-T has published a Recommendation K60 (02-2008) [14] which proposes a measurement method and target levels to be used in case of interference with radio service caused by the radiation from wire-lines using broadband systems including the PLT. This recommendation is addressed to all parties involved with the investigation of complaints of radio interference including the national responsible body.

In parallel, the WG10 of CENELEC 205A which decided to develop an independent CENELEC standard and a New Work Item Proposal was presented [15].

Its aim was to propose a dynamic computer model of the mains network.

The idea was that if the feasibility of a computer model is proved, it can be used to verify the compliance of a PLC modem to the requirements of the LV Directive and the EMC Directive.

The model should help to understand better the interaction between the LV network and the PLC equipment. In the opinion of the New Work Item Proposal, the lack of understanding can be the cause of the slow progress in the development of standards in this field.

However, several National Committees did not support the work (Denmark, The Netherlands and Norway), or abstained like Switzerland [16].

The idea to use a computer model is not new in standardization. In 1990, a control device was connected to a virtual building with its heating system to test how the control device is working.

The results of the «virtual» tests were reliable and could be used to test the compliance of the control system with the standard.

The problem with the proposal of the WG10 was that the document gives no details how the modem under test can be connected to such a "virtual" model and how the test should be performed.

As a result, at the SC205A/WG10 meeting on 23–24 October 2006, it was considered that although the opinions on the SC205A/Sec0192/NP were divided, sufficient support was not obtained in order to determine the BT (CENELEC Technical Bureau) to approve a new project [17].

On the other hand, in September 2005, the SC205A/WG10 published a harmonized standard EN 50412-2-1 [18] to cover the essential immunity requirements of EC Directive 2004/108/ECC (repealing the Directive 89/336/ECC) [18]. This standard applies to PLT equipment using signals in the frequency range 1.6 MHz to 30 MHz to transmit information on low voltage electrical system, either on the public supply system or within in-house installations.

3.3 Coexistence Standard

The coexistence standards are needed to provide:

- Interoperability of products of different manufacturers;
- The coexistence in the same network of products from different manufacturers.

These standards should define the signal modulation in case of a beacon concept and the data transmission protocols.

Several entities have prepared such standards: a Working Group of PHY/MAC of IEEE P1901, the CEPCA (Consumer

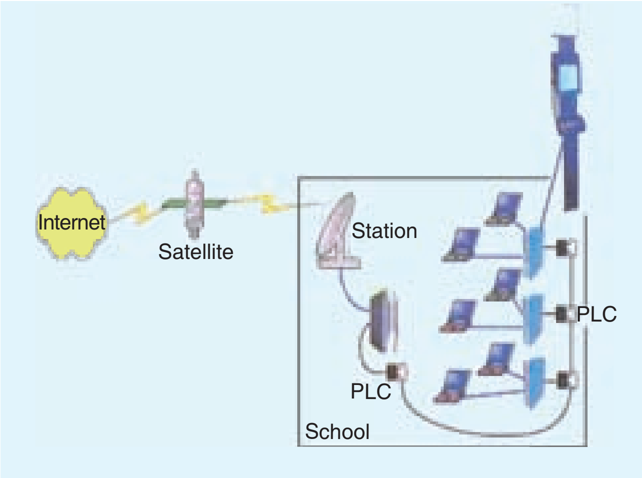

Fig. 5. The GESAC project in Brazil.

Electronics PLC Alliance) and ETSI PLT [20]. Moreover, ITU-T recently released (December 2008) a specification G.hn [21] for the "next generation" home network technology that will take into account the coexistence providing an evolution path from today's existing-wire home networking technologies including Multimedia over Coax Alliance over coax, HomePNA over coax and phone wires and Homeplug AV, Universal Powerline Association (UPA) and HD-PLC over powerline.

4. Regulatory Situation

Even in the absence of standards, the regulatory bodies of different countries have encouraged the implementation of PLC networks.

4.1 USA

In the USA, the Report and Order of 14 October 2004 [22] reaffirmed with minor changes on August 2006 [23]:

- Defines in the frequency range 1.705–30 MHz a limit of 30 uV/m at 30 m for all «access» installations (links between a transformer and a group of houses);
- Defines restricted bands of operation and exclusion zones, with lower limits:
  - Near the ocean coasts;
  - Near military installations;
  - Near radio telescopes and aeronautical stations.

4.2 European Union

In the European Union, the European Commission issued the Recommendation of April 6, 2005 [24].

This recommendation is similar to the « Report and Order » of the FCC. It states that:

- No preliminary authorization for the deployment of a PLC network is required;
- The states can define exclusion zones;
- In case of conflict, each state can apply its own limits.

In-house PLC equipment is considered telecommunication equipment and regulated in Europe according to the EMC Directive 2004/108/EC, i.e. as any other electrical device as it is used for building up home LANs, which are private (not-public) networks.

According to the new EMC Directive 2004/108/EC, fixed installations (e.g. including the PLT apparatus) do not need CE certification, but only CE certified products can be installed in their network. However, the installation shall comply with the essential requirements of the EMC Directive. For example, the pr EN 50529-3 is a candidate harmonized standard that could be used to demonstrate the compliance of the PLT network with the EMC Directive.

4. 3 China

In China, the regulatory authority is the Ministry of Industrial Telecom. No regulatory, formally binding document has been issued for the moment.

The deployment is performed under the direction of the Telecommunication Center of the Chinese National Grid.

In 2005, a Mandate of the National Grid to the North China Electric Power University to develop a standard and measurement method has been issued [25].

Without any regulatory document, in 2005, some 34,000 PLC customers were connected in Beijing to the internet through the power distribution network.

5. PLC is Looking for New Types of Applications

5.1 A Project for Remote Areas in Brazil

The GESAC project is aimed to create in Brazil the so-called "digital islands" [26]. The idea is:

- To connect by satellite the poor rural regions of the country to the communication network;
- To distribute the information using PLC inside the cities or even villages.

The "Digital island" was introduced as a pilot trial in the city of Barreirinhas, a rural area in northeast Brazil, with a population of 13,000 inhabitants and a human development index = 0.55, one of the lowest in the country (fig.5).

5.2 Coordination of Distributed Power Generation (Smart Grid) [27]

An example of Distributed Power Generation (DG) is shown in fig. 6.

In a network scenario involving DG, the operator needs to find an optimal way to control the power grid. The following options or combinations can be defined:

- Controlling the DG.
- Use of energy storage. This approach is in particular used together with wind turbines and photo-voltaic systems;
- Influencing user behaviour by specific power tariffs.

The DG uses necessitates information flow from and to all the equipment in the distribution network.

5.3 OPERA Project

The O.P.E.R.A (OPEN PLC European Research Alliance) [28] is a co-financed European Project within the VI Framework

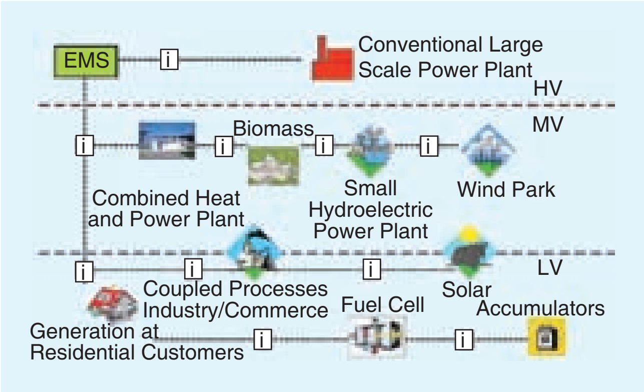

Fig. 6. Example of distributed power generation.

program that deals with PLT. Its main target is the definition of technical specifications and the implementation of advanced PLT solutions using new IP services. The main goal of this project is to speed up the standardization process providing efficient and low cost PLC systems.

6. Conclusion

After nearly 10 years since this new technology was proposed, the radiation of PLC networks and the conducted disturbances from the products are still a very controversial question.

On the other side we see that:

- In practice these potential noise seems to give no problems;
- Experimental or commercial deployments are working without meaningful complaints.

It seems that the companies which install PLC are hesitating between a desire to increase their networks and a potential risk they don't want to incur.

However, the very favorable regulatory approach taken by both the European Commission and the FCC in the US should give an impulse to the commercial deployment and/or to new applications.

The impact of large countries such as China and Brazil in the PLC world is still not very significant, but can change completely the amount of deployment in the coming years.

References

[1] G. Goldberg, "Evaluation of power line communication systems," in *Proc. 15th Int. Wroclaw Symp. EMC*, June 27–30, 2000, pp. 103–106.
[2] D. Hansen, "Megabits per second on 50Hz power lines," in *Proc. 15th Int. Wroclaw Symp. EMC*, June 27–30, 2000, pp. 107–110.
[3] K. Dostert, "EMC aspects of high speed powerline communication," in *Proc. 15th Int. Wroclaw Symp.and Exhibition on EMC*, Wroclaw, 2001, pp. 98–102.
[4] *Proposed Amendment to CISPR 22 to Clarify Its Application to Telecommunication Systems with Regard to the Method of Disturbance Measurement at ITE Ports Used for PLC*, IEC CISPR/I/26/DC, Dec. 21, 2001.
[5] European Commission, *Standardization Mandate Addressed to CEN, CENELEC and ETSI Concerning Electromagnetic Compatibility (EMC) in Telecommunication Networks*, Mandate 313, Aug. 7, 2001.
[6] Univ. of Dortmund, *Contributions to CISPR/I/26/DC*, Jan. 26, 2002.
[7] *Amendment to CISPR 22. Limits and Method of Measurement of Broadband Telecommunication Equipment over Power Lines*, IEC CISPR/I/145/NP, Jan. 28, 2005.
[8] IEC CISPR/I/186/DC, Mar. 17, 2006. "PT PLT: Limits and method of measurement of broadband telecommunication equipment over power lines".
[9] IEC CISPR/I/211/DC, July 15, 2006. PT PLT: Limits and method of measurement of broadband telecommunication equipment over power lines
[10] IEC CISPR/I/191/INF Compilation of comments on CISPR/I/186/DC
[11] *CISPR 22 – Limits and Method of Measurements of Broadband Telecommunication Equipment over Power Lines*, IEC CISPR/I/257/CD. August 02, 2008.
[12] *Proposed Approach on EMV Emission Requirements for PLT*, IEC CISPR/I/269/DC. June 20, 2008.
[13] *Confirmed Minutes of the 16th Meeting of the CENELEC/ETSI JWG on EMC of Conducted Transmission Networks Held on 21/22 February 2006*, CENELEC SC205A/Sec0182//INF/rev1, Apr. 2006.
[14] *Emission Levels and Test Methods for Wire-Line Telecommunication Networks in Case of Radio Interference*, ITU-T Recommendation K60, Feb. 2008.
[15] *New Work Proposal on PLC*, CENELEC SC205A/Sec0192/NP, June 2006.
[16] *Comments on the New Work Proposal on PLC*, CENELEC SC205A/Sec0192/CC, Sept. 20, 2006.
[17] *Notes on 43rd Meeting on 23rd and 24th October 2006 at BSi Group Headquarters*, CENELEC SC205A/WG10 (Chiswick) 2, Chiswick, London.
[18] *PLC Apparatus and Systems used in Low-Voltage Installations in the Frequency Range 1.6 MHz to 30 MHz – Immunity Requirements*, EN 50412-2-1. September 2005.
[19] *EU Council Directive 2004/108/EC on the approximation of the laws of the EU Member States relating to electromagnetic compatibility and repealing Directive 89/336/EEC* - 15 December 2004.
[20] W. Scott, (Power Line Products Manager, AvistoTelecom), "Coexistence standards," Technical and Regulatory Workshop, Nice, 26 June 2006.
[21] *ITU-T Recommendation G.9960 Next Generation Wire Line Based Home Networking Transceivers.* December 2008. G9960.
[22] Federal Commission on Communication, "Report and order," FCC 04-245, Oct. 14, 2004. Washington, D.C. 20554.
[23] Federal Commission on Communication, "Report and order," FCC 06-113, Aug. 3, 2006. Washington, D.C. 20554
[24] Commission of the European Communities, "Commission recommendation of 6 April 2005 on broadband electronic communication through power lines," Brussels, Document No. C10316, Apr. 2005 .
[25] W. Zhang, Z. Yuan, X. Cui, M. Ianoz, S. Qi, and X. Li, "PLC studies in China as a contribution to the development of international standards," in *Proc. 4th Asia-Pacific Conf. Environmental Electromagnetics, CEEM'06*, Dalian, Aug. 1–4, 2006. pp. 759 - 764.
[26] P. Jatoba, "Report to the PLC forum," presented at the 3rd PLC World Summit, Brussels, Dec. 15–16, 2005.
[27] M. Koch, "Powerline communications for the coordination of distributed generation and key aspects for inter-working with UMTS," Ph.D. thesis, Univ. of Duisburg-Essen, Oct. 31, 2006.
[28] OPERA – IST Integrated Project No 507667, funded by EC 2005.

Abbreviations

ADSL	Asymmetric Digital Subscriber Line
AMN	Artificial Mains network
CD	Committee Draft
CDV	Committee Draft for Vote
CENELEC	Comité Européen de Normalisation Electrotechnique
CEPCA	Consumer Electronics PLC Alliance
CISPR	Comité International Spécial pour le Pertubations Radioelectriques
DC	Document for Comment
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
IEC	International Electrotechnical Commission
ITU	International Telecommunication Union
JWG	Joint Working Group
LCL	Longitudinal Conversion Loss
NC	National Committee
NWIP	New Work Item Proposal
OPERA	Open PLC European Research Alliance
PLC	Power Line Communications
PLT	Power Line Technology
PT	Project Team
UPA	Universal Powerline Association

Biographies

Mariano Giunta received the degree in Electronic Engineering from the Politecnico of Torino-Italy in 1989. In the same year, he joined Telecom Italia/TILAB (Telecom Italia Laboratory, whose main activities are engineering, innovation and testing in the field of telecommunication); since that time, he has been involved in studies, standardization and testing activities on EMC telecommunication topics. Currently, he is responsible for the Telecom Italia EMC laboratory. He has lectured on EMC measurements at the Politecnico of Torino and he is active in several EMC related national and international standardization committees including IEC, ETSI, and CENELEC.

Michel Ianoz taught EMC as a Professor of the Electrical Department of the Swiss Federal Institute of Technology of Lausanne until 2001. He is now an honorary professor. He was engaged in research activities concerning the calculation of electromagnetic fields, transient phenomena, lightning and EMP effects on power and telecommunication networks and power line communication. Professor Ianoz is a past Chairman of the Subcommittee 77B (HF phenomena) of the International Electrotechnical Commission (IEC). He is an EMP Fellow, IEEE Fellow and Doctor Honoris Causa of the Technical University of Saint-Petersburg.

EMC