PLC PERFORMANCE EVALUATION THROUGH A POWER TRANSFORMER USING PRIME

Eng. **Codrin MALES** PhD S, Prof. Eng. **Valentin POPA** PhD,
Eng. **Alexandu LAVRIC** PhD S, Eng. **Ilie FINIS** PhD S

Stefan cel Mare University of Suceava, Romania

REZUMAT. În această lucrare este realizată evaluarea performanţelor comunicaţiei PLC (Power Line Communications) în bandă îngustă utilizând protocolul PRIME. Testele au fost efectuate în banda CENELEC A (3-95 kHz). Studiul se axează pe transferul de date atunci când comunicaţia este realizată printr-o linie electrică de 100m lungime şi printr-un transformator. În cadrul testelor efectuate a fost variat TBS-ul (Transfer Block Size) astfel încât numărul de pachete să fie acelaşi folosind modulaţia DBPSK (Differential Binary Phase Shift Keying). Valorile parametrilor PER (Packet Error Rate), SNR (Signal to Noise Ratio) şi viteza de transfer au fost analizate în cazul comunicaţiei bidirecţionale.

Cuvinte cheie: DBPSK, PRIME, PER, SNR, transformator.

ABSTRACT. In this paper a performance evaluation of narrowband PLC (Power Line Communications) using PRIME protocol is made. Tests were done in the CENELEC A band (3kHz - 95 kHz). The study focuses on the transfer of data when communication is achieved through a power line of 100 m long and through a transformer. In the tests the TBS (Transfer Block Size) was varied, so that the number of data packages transferred to be the same, when DBPSK (Differential Binary Phase Shift Keying) modulation has been used. Values of PER (Packet Error Rate), SNR (Signal to Noise Ratio) and transfer data rate were analyzed for bidirectional communication.

Keywords: DBPSK, PRIME, PER, SNR, transformer.

1. INTRODUCTION

Power Line Communications (PLC) uses the power lines as propagation environment. A power network has the structure: low voltage (LV) power lines, medium voltage (MV) power lines, high voltage (HV) power lines and very high voltage (VHV) power lines. The four main segments of the power network are linked through step-down power transformers. PLC use in most of cases only two segments of the network, the LV and MV power lines. The two segments are being used for communication of two application types: broadband and narrowband [1].

In this paper a narrowband power line communication performance evaluation is made. This type of communication is used for metering applications of private homes and industrial facilities. Frequency band used in Europe is CENELEC A (3 kHz – 95 kHz), as is specified in the standard EN 50065-1.Metering solutions available until now have been using communication technologies as GPRS (General Packet Radio Service) and WiFi in most of the systems. Data are undertake straight from meters or from a concentrator located in the secondary winding of a MV/LV transformer. Communication between meters and concentrator is made with the use of PLC modems, and from the concentrator to the data base of the system through wireless technologies. The automation of reading and administrating of electric, water and gas meters merge with possibilities of the power line smart grid [2].

Power Line Communications are settle by the international standard IEEE P1901 which has been published at the beginning of the year 2011. A standard that settles the narrowband PLC will be published as IEEE P1901.2. For it's development two proposals have been sent to the project group: PRIME and PLC-G3. The two proposed protocols recommend as a solution for communication through power lines environment, one which is affecting communication's performances by the mean of noise, the use of multiplexing technique OFDM (Orthogonal Frequency-Division Multiplexing) and of modulations: DBPSK (Differential Binary Phase Shift Keying), DQPSK (Differential Quadrature Phase Shift Keying) and D8PSK (Differential Eight-Phase Shift Keying) [3]. This modulation technique is proposed as a better solution for the replacement of DSSS (Direct-Sequence Spread Spectrum) used until now in narrowband communication systems. The use of OFDM can make power line communications improve by the mean of data transfer speed, communication distances and working in noisy environments [4]. Due to the use of communication technique based on OFDM, PLC can ensure data transfer on long distances on LV and MV power lines. Communication between the two segments of the power network can be made without the use of bypass equipments. The most important protocols that precede PRIME and PLC-G3 are: X-10, CEBus, Lontalk, KNX PL 110 and IEC 61334 [2][5], which have a low performance level.

Power line environment present different types of noise being random, desultory and variable, with multiple sources. Noise can affect communications in MV and LV power lines, it's origin can be: connections and disconnections of devices from the power line, induction from appliance devices and radiations from wireless communications. Noise that affect power line communications can have the following nature: continuous noise, impulsive noise, narrowband noise, channel frequency response and white noise [6].

Communications between the segments of an electric grid is required because bypass equipment can be eliminated from the metering system architecture, reducing costs and maintenance. This solution has it's disadvantages, the main one being the receiving of the PLC signal on the other side of the transformer at a certain distance. The receiving of data can be problematic because the signal suffer attenuation while passing the transformer. A study of PLC using PLC-G3 is presented in [7] for communication on LV and MV lines, and from LV to MV and vice versa, with encouraging results.

The rest of the paper is organized as follow: Section II gives an overview of PRIME specifications, followed by tests setup in section III. In section IV are presented field tests results when communication was made through a transformer and on a LV power line. Conclusions of the paper are presented in section V.

2. PRIME

PoweRline Intelligent Metering Evolution (PRIME) is the proposed protocol for PHY and MAC layers of power line communications stack from PRIME Alliance regarding the development of the IEEE P1901.2 standard. The PRIME project took life at the initiative of the Iberdrola company from Spain, to which joined important companies such as: Itron, ADD Semiconductor, Current, Landis Gyr, STMicroelectronics, Texas Instruments, ZIV, Sagemcom and others. PRIME propose the use of a part of CENELEC A frequency band with a bandwidth of 47,36 kHz located above 40 kHz. The frequencies under 40 kHz are being affected by major perturbations. Communication will use 97 carriers equally spaced at 0,488 kHz in the 41,9 kHz – 88,8 kHz frequency band. Spreading technique to be used is OFDM and the modulations: DBPSK, DQPSK and D8PSK. Using D8PSK can be obtained a theoretical data transfer speed of 141 kbps. Medium access technique used is CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) [8].

3. TEST SETUP

The power line grid is becoming a centralized and automated structure from access point of view and control of last mile equipments, like the meters reading process. In this paper an evaluation of protocol PRIME performances has been made, in three test scenarios. The communication between modems was bidirectional, as shown in Figures 1 and 2.

The configuration test scenarios are:

1. Communication between PLC modem M1 and M2 when they are connected to a power line at a 100m distance between them.
2. Communication between PLC modems when one is connected to the primary winding and the other one to each of the two secondary winding of the transformer at a distance of 5m on each side.
3. Communication between PLC modems when one is connected to the primary winding at a distance of 5m and the second one to each of the two secondary windings of the transformer at a distance of 100m.

Communication is realized through a transformer, where signal can suffer attenuation of 40 dB, and through an electric power line where the signal can suffer attenuation of 30 dB [9]. During the tests the following parameters have been analyzed: PER (Packer Error Rate), SNR (Signal to Noise Ratio) and Tx (transfer speed). The communication was realized as a bidirectional one using the DBPSK modulation which can guarantee a better data transfer speed and a high level of immunity to interferences [8].

PLC modems used in tests were programmed with the software given by the manufacturer. The transformer used in tests has a ferromagnetic core, is cooled in air, the primary winding has a three-phase configuration and was used in tests in a mono-phase configuration. His structure is made from a primary winding which was connected to the 220V power grid and two secondary windings, with galvanic separation, which provide a 66V and a 14,6V voltage values.

Communication topology analyzed in scenario 1 consists in evaluation of studied parameters on a power line of 10m long connected to the LV power grid as shown in Figure 1.

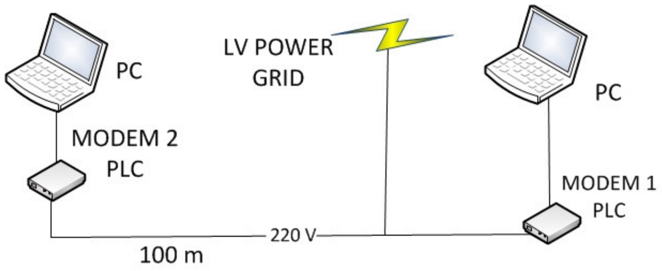

Fig. 1. Power line communication test

As presented in scenarios 2 and 3 the communication was realized with two PLC modems connected to the primary winding and to the secondary windings of the transformer at a time. This can be observed in Figure 2.

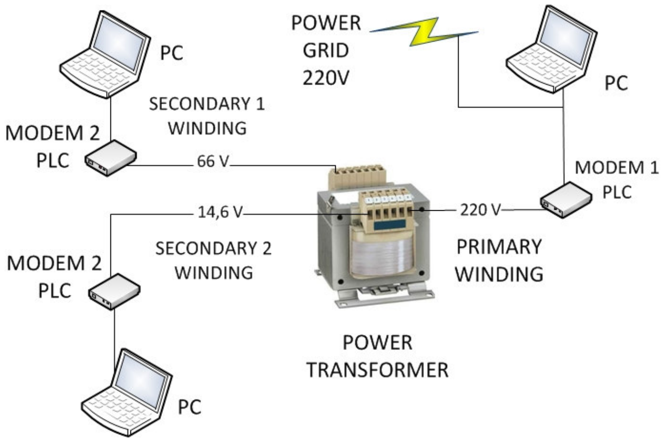

Fig. 2. Transformer communication test

The transfer was made between two PC units connected at the PLC modems through USB cables as Figure 1 and Figure 2 show. Between the two modems the transfer was made in both directions.

For test purpose there were used pairs of files and data transfer block sizes (TBS) of 10kB/256B, 20kB/512B and 40kB/1024B. The purpose of the combinations was to have the same number of 40 packets of data being transferred with the variation of transfer packet size. PLC modems were configured in AGC (Automatic Gain Control) mode with the use of a correction error FEC (Forward Error Correction) type.

4. TEST RESULTS

In this section are presented results from the 3 scenarios presented in previous section. In table 1, as described in scenario1, are presented the PER, SNR and data transfer speed values when the communication is made through a power line 100m long. This situation is shown in Figure 1.

Table 1

Transfer M1 ↔ M2

M1 -> M2				
File	**TBS (B)**	**PER (%)**	**Tx (kbps)**	**SNR (dB) M1/M2**
10kB	256	2,5	3,7	18/18
20kB	512	0	6,2	18/18
40kB	1024	0	7,2	16/9
M2 -> M1				
File	**TBS (B)**	**PER (%)**	**Tx (kbps)**	**SNR (dB) M2/M1**
10k	256	0	5,1	9/18
20k	512	0	6,2	12/18
40k	1024	0	7,2	12/18

According to obtained data, can be observed that the transfer has performed with success at speeds reaching 7,2 kbps. Packet loss of 2,5% can be noticed when the transfer packet size was of 256B on the M1-M2 path. The communication is successfully in both directions in all file/packet size combinations. This performance is achieved due to a high level of SNR detected by PLC modems at the communication time.

In Figure 3 is presented the variation of SNR and RSSI (Received Signal Strength Indicator) at M2 during the file transfer of 10kB with the TBS value of 256B.

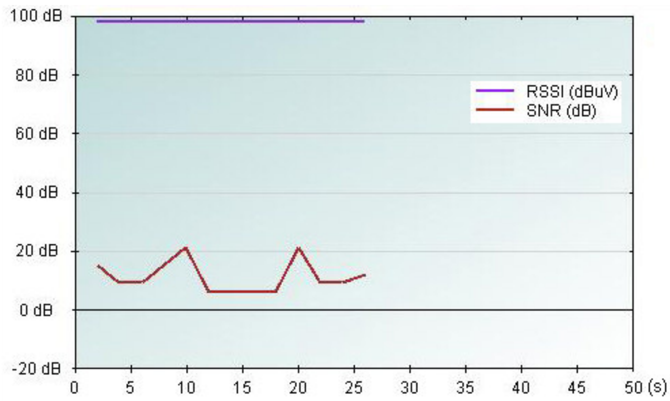

Fig. 3. Power line 10kB file transfer at 100m distance

As can be observed the noise level is variable at M2 although it is connected at 100m from the point where the test power line is connected to the LV grid, as shown in Figure 1. The duration time of the transfer in this situation is 27s.

Table 2 show the obtained data during the transfer between the primary winding and the first secondary winding of the transformer, as presented in scenario 2 and shown in Figure 1. The distances between modems and windings are of 5m.

Table 2

Transfer P ↔ S1

P -> S1				
File	**TBS (B)**	**PER (%)**	**Tx (kbps)**	**SNR (dB) P/S1**
10k	256	2,5	3,2	15/12
20k	512	2,5	4,2	9/21
40k	1024	5	5,3	9/21
S1 -> P				
File	**TBS (B)**	**PER (%)**	**Tx (kbps)**	**SNR (dB) S1/P**
10k	256	2,5	1,7	21/12
20k	512	2,5	2,7	21/12
40k	1024	5	4,2	21/12

Packet loss is present in all transfer configurations. The highest value of PER of 5% can be noticed when transfer block size is 1024B. In the other cases the values of PER are half of this value. Data transfer speed is variable with values from 1,7 kbps to 5,3 kbps, being proportional with the growth of the TBS. The noise induced by the transformer is not affecting the communication, the SNR ration is variable but with high values in most cases.

Table 3 presents the interested parameters, as described in scenario 3, when the distance between PLC modem M1 and the primary winding is 5 m and the distance between PLC modem M2 and the secondary winding S1 of the transformer is 100m. The configuration is shown in Figure 1.

Table 3

Transfer P ↔ S1 at 100m

P -> S1				
File	**TBS (B)**	**PER (%)**	**Tx (kbps)**	**SNR(dB) P/S1**
10k	256	15	0,6	9/21
20k	512	25	0,9	6/21
40k	1024	25	1,4	6/18
S1 -> P				
File	**TBS (B)**	**PER (%)**	**Tx (kbps)**	**SNR(dB) S1/P**
10k	256	100	0	18/9
20k	512	100	0	21/9
40k	1024	100	0	18/6

An important packet loss can be observed, with values of 25% in worst cases when communication was made in the primary-secondary windings direction. Communication is made with packet loss in all configurations, a smaller value of 15% is achieved when the packet block size is 256B. The high values of PER might be justified by the low signal level detected by M1, the highest values of SNR being 9 dB. When data transfer was successful the highest transfer speed was 1,4 kbps. In the case when the length of the power line grow at 100m in the secondary winding the transfer could not be realized when communication was made in the secondary-primary winding direction. The packet loss at the transfer in the both directions can be justified by the attenuation in the power line on it's length.

According to scenario 3, as presented in Figure 2, the variation of SNR and RSSI is shown in Figure 4 at PLC modem M1 when the 10kB file was transferred with the TBS value of 256B. The behavior was observed when the transfer from table 3 was made for this case.

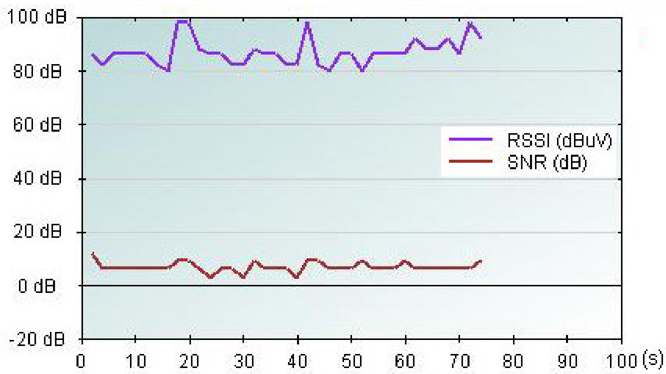

Fig. 4. Transformer 10kB file transfer at 100m distance

A permanent variation of the two parameters can be noticed for the all transfer period of time. The transfer was made between M1 and M2 as presented in scenario 3. The noise in the primary winding and the length of the power line make the file transfer perform with difficulty, a permanent adaptation of the signal level being required during the all period of time of the transfer of 75s. This period of time transfer is significantly higher then in the case of the transfer through the power line of 27s as Figure 3 shows.

In table 4 are presented the registered values of observed parameters when communication was made as described in scenario 2. The data transfer was made between the primary and the secondary S2 windings of the transformer.

Table 4

Transfer P ↔ S2

P -> S2				
File	**TBS (B)**	**PER (%)**	**Tx (kbps)**	**SNR(dB) P/S2**
10k	256	5	3	12/18
20k	512	0	6,2	9/18
40k	1024	0	7,1	9/21
S2 -> P				
File	**TBS (B)**	**PER (%)**	**Tx (kbps)**	**SNR(dB) S2/P**
10k	256	0	3,2	18/12
20k	512	0	6,1	18/12
40k	1024	0	6,3	18/15

In this case the parameters had better values then in the case of transfer through secondary S1 winding at the same distance. The file transfer in this case is made with packet loss of 5% in one situation, and in the case of the file transfer through S1 (table 2) the packet loss has a minimum of 2,5% in all situations.

Speed transfer is growing with the increasing of the packet size reaching values of 7,1 kbps. The values in situation when TBS is 512B and 1024B in direction S2-P are very close. This might be due to time needed for error correction in the packet block, but his number of errors is not big enough to make the packet be declared lost and retransmission required. The decrease of PER values can be justified by the reduced number of coils in the secondary S2 winding, that don't allow a high level of noise at this distance from the transformer.

At the grow of length to 100m between S2 and M2 a file transfer was unsuccessful under no circumstances or configuration. The switch of modulation to DQPSK or D8PSK didn't result in positive results with any packet size. The presence of a reduced number of coils determine a low magnetic field that can't ensure communication at this distance of 100m.

5. CONCLUSIONS

In this paper results from tests made on a LV power line and a transformer of PLC using protocol PRIME in CENELEC A band are presented. In this evaluation performance tests of this protocol have been made, when communication is made through a transformer without bypass equipments. Tests made on the 100m long power line show the potential of communication at this distance with PER of 0% in most cases. Tests made on a smaller distance between modems and transformer show the possibility of communication with packet loss of maximum 5%. When the distance on the secondary winding side was increased to 100m the transfer was possible only on primary-secondary windings direction with a PER of 25% maximum. In the other cases of communication at 100m, from secondary winding S1 to primary winding and from secondary winding S2 to primary winding in both directions, the transfer was not possible at this distance with neither modulations available. Power line communications can be made through a transformer using protocol PRIME but possibilities are limited.

ACKNOWLEDGMENT

This paper was supported by the project "Improvement of the doctoral studies quality in engineering science for development of the knowledge based society-QDOC" contract no. POSDRU/107/1.5/S/78534, project co-funded by the European Social Fund through the Sectorial Operational Program Human Resources 2007-2013.

BIBLIOGRAPHY

[1] H. C. Ferreira, L. Lampe, J. Newbury, T. G. Swart, *Power Line communications – Theory and Applications for Narrowband and Broadband Communications over Power Lines*, **Ed. Wiley, 2010.**

[2] C. Maleş, V. Popa, *Analiza evoluţiei comunicaţiei prin liniile electrice de exterior*, **Scientific Seminar „Sisteme Distribuite", Ştefan Cel Mare University Of Suceava, România, 2011**

[3] M. Hoch, *Comparison of PLC G3 and PRIME*, **International Symposium on Power Line Communications (ISPLC), 2011.**

[4] S. Souissi, A. B. Dhia, F. Tlili, C. Rebai, *OFDM modem design and implementation for narrowband Powerline communication*, **International Conference on Design & Technology of Integrated Systems in Nanoscale Era, 2010**

[5] L. F. Montoya, *Performance Overview of the Physical Layer of Available protocols*, **Donetsk National Technical University, 2006.**
[6] A. Llano, A. Sendin, A. Arzuaga, S. Santos, *Quasi-synchronous Noise Interference Cancellation Techniques Applied in Low Voltage PLC*, **ISPLC, 2011**
[7] Electricite Reseau Distribution France, *PLC G3 Physical Layer Specification*, **Project PLC G3 OFDM, 2009**.
[8] PRIME Alliance, *Draft Standard for PoweRline Intelligent Metering Evolution*, **Version 1.3E, 2010.**
[9] K. Razazin, M. Umari, A. Kamalizad, V. Loginov, M. Navid, *G3-PLC Specification for Powerline Communications: Overview, System Simulation and Field Trial Results*, **ISPLC, 2010**.

About the authors

Eng. **Codrin MALES**, PhD. S.
University „Stefan cel Mare” of Suceava, Romania.
email:cmales@eed.usv.ro

Graduated at „Ştefan cel Mare” University of Suceava, Faculty of Electrical Engineering and Computer Science in 2007. In 2010 he obtained a Master degree in Visual Arts, Design and Imagine Editing powered by Computer. Started PhD program in 2010 with the research area Power Line Communications at the same University.

Prof. Eng. **Valentin POPA**, PhD.
University „Stefan cel Mare” of Suceava, Romania.
email:valentin@eed.usv.ro

Graduated at the "Gheorghe Asachi" Technical University of Iasi, Electrical, Electronics and Telecommunications Faculty, study program- Electronics and Telecommunications in 1989. After finishing the faculty, he followed a PhD. study and graduated in 1998. Since 1992, he workes at “Ştefan cel Mare” University of Suceava receiving the title of Prof. in 2005. His main research areas are: RFID systems, intelligent sensor networks and wireless data transmission systems. From 2009, he is PhD coordinator. Since his employment in the academic environment, he has been the responsable for multiple grant agreements. Currently, he is the rector of the “Ştefan cel Mare” University of Suceava.

Eng. **Alexandru LAVRIC,** PhD. S.
University „Stefan cel Mare” of Suceava, Romania.
email:lavric@eed.usv.ro

Graduated at the "Gh. Asachi" Technical University, Faculty of Electronic Telecommunication and Information Technology in 2009. In 2008 he obtained a Bachelor degree in Administrative Sciences from "Ştefan cel Mare" University of Suceava, Faculty of Economics and Public Administration and in 2010 obtained a Master degree in Business Affairs from the same University. Since 2010, he is a PhD attending student in Electronics and Telecommunications, and also pursuits a master diploma in Computer and Communications Networks. His main research areas are: lighting control systems, WSN and wireless communication technologies.

Eng. **Ilie Finis,** PhD. S.
University „Stefan cel Mare” of Suceava, Romania.
email:ifinis@eed.usv.ro

Graduated at the „Ştefan cel Mare” University of Suceava, Faculty of Electrical Engineering and Computer Science in 2009. Since 2009, he pursuits a master diploma in Computer and Communications Networks from the same university. He also is, a PhD attending student in Electronics and Telecommunications with the PhD. thesis „Contributions regarding the implementation of RFID technology in warehouse management."