Field trial deployment for the evaluation of G3-PLC performance in the medium voltage grid

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ABSTRACT

Analyzing the potential of G3-PLC in the MV part of the grid is of high interest. Indeed, in the context of using G3-PLC for smart metering applications in the low voltage (LV), it is important to evaluate the possibility to extend the communication range of the MV part by crossing the MV/LV transformers. In addition, G3-PLC is also a potential communication candidate to manage the MV network operations. This paper presents the experimental setup deployed in a medium voltage (MV) grid in Belgium in order to evaluate the performance of G3-PLC systems as well as to identify the main sources of degradations (noises, power consumption, distributed productions, etc.).

INTRODUCTION

The work presented in this paper has been realized in the context of a consortium consisting of 4 members sharing an interest in the study of the G3-PLC performance in the MV part of the Grid. The consortium is composed of ORES (DSO), Nexans (equipment manufacturer), Laborelec (Laboratory specialized in power line properties measurement) and the Electromagnetism and Telecommunication Department of the Faculty of Engineering of UMONS (Academic partner).

ORES is a DSO operating electricity and gas distribution grids in Wallonia (the southern part of Belgium) for about 1.800.000 connection points in 197 municipalities. To make deployment of reliable smart grids and smart metering possible, the telecommunication infrastructure choice is fundamental and critical. ORES is currently testing G3-PLC for smart meters communications on low voltage grids. The use of this technology on MV grids could also be very interesting for DSOs as an extension of their current communication infrastructure i.e. remote control. That is why ORES, with the consortium, has decided to concretely test G3-PLC communications and measure performance on the MV grids.

The main goals shared by the consortium are: 1) to evaluate the feasibility of using G3-PLC communications in the FCC band on MV grids (lines and cables) for smart metering data communications and remote grid operation, and 2) to identify the necessary equipment required to achieve and monitor G3-PLC communication.

Communication on a MV grid presents multiple challenges, mainly because the transmission distances to cover between emitting and receiving ends are considerable. This results in potentially more signal attenuation and more distortion.
Moreover, for a communication to take place between the LV and the MV parts of the grid, the signal has to cross the MV/LV transformer. This crossing deteriorates the signal drastically such that additional devices have to be placed for the communication to pass through.

In order to rise up to the different challenges presented previously, each member of the consortium has to play its part.

Firstly, specialized equipment used to inject and receive PLC signal on the MV line has to be conceived and installed. This role is fulfilled by Nexans by developing and providing the couplers and other devices injecting G3-PLC signals on the MV.

Secondly, in a feasibility test of a new communication technology, it is also very interesting to grasp the phenomena influencing the communication performance. It is made possible by using the measurement toolbox developed by Laborelec [1] to obtain information on the noise and the characteristics of the communication link.

Thirdly, the University of Mons, Belgium (UMONS) adds its expertise in the analysis and exploitation of the relevant data obtained during the field trial. More precisely, the role of the university is to develop instruments to obtain meaningful data pertaining to the performance [2] of the communication and to analyse those data to study the usability of G3-PLC on an MV grid.

Finally, ORES as a DSO provides its network, its technical support and gives a crucial practical point of view in guiding the tests of the field trial.

G3-PLC STANDARD

G3-PLC is defined in the ITU-T G.9903 [3] and is specifically thought to transmit digital signals on power line channel. As PLC channels are harsh media, the standard uses several advanced transmission techniques inspired by wireless transmission techniques. The main modulation types used in the standard are Phase Shift

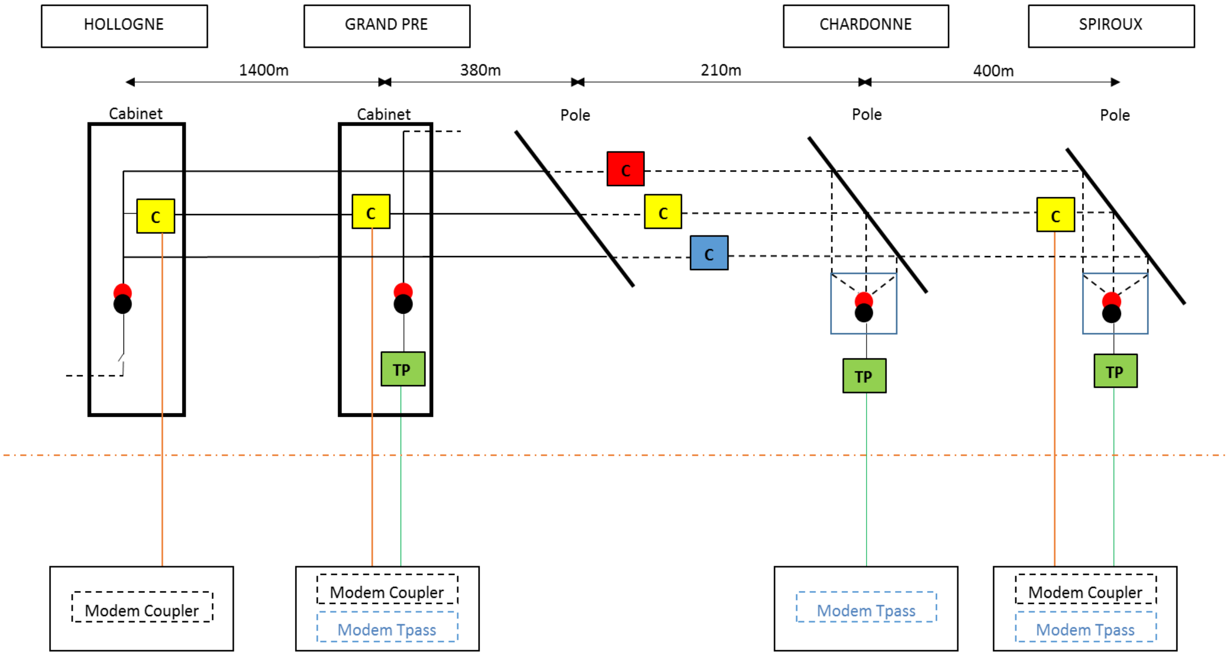

Figure 1: Marche-en-Famenne field trial setup (C=Coupler; TP=Tpass)

Keying based and comprised DBPSK, DQPSK, and D8PSK. 16QAM schemes are also defined. To even further protect the data, a robust modulation scheme called ROBO mode is defined. It uses the most robust modulation (DBPSK) and repeats each data block four times. The standard can be used in different frequency bands. The standard defines the use of G3-PLC for instance in CENELEC-A (3-95 kHz) and FCC (100-490 kHz) band. As explained previously, ORES would like to evaluate the use of MV lines as an extension of its LV communication network. In that way, the need for data throughput on the MV line is higher. Given the situation it was decided to use FCC band on MV line transmission during the field trial due to the increased achievable throughput compared to CENELEC-A.

FIELD TRIAL SETUP

In this part, the topology and the specificities of the field trial will be described alongside the equipment used. The field trial takes place in a rural area of Belgium near Marche-en-Famenne. The topology of the PLC line is presented on figure 1. It consists in an MV line that is about 2.4km long containing four MV/LV transformers. The scheme is presented on figure 1 where the dotted lines represent aerial lines and plain lines represents underground cables. The MV network is fed from the Grand Pre transformer of the figure 1. Every MV/LV transformer is connected to a LV network except at Hollogne which is used in case of maintenance. At each transformer, two types of equipment can be found to inject signals. The first is a coupler designed by Nexans which injects and receives directly the communication signals on and from the MV lines. The second device makes it also possible to inject and receive PLC signals on the LV side of the transformer. This device is manufactured by Nexans and called a Tpass. It is a passive coupling device used to cross LV/MV transformers in both directions by injecting the PLC signal through the parasite capacitances of the transformer. The Couplers and Tpasses are designated respectively *C* and *TP*. With this equipment, it is possible to study the communication’s behaviour in different scenarios. For instance, it is possible to study the characteristics of the communication on an aerial line between Chardonne and Spiroux transformers, the impact of an aerial/subterranean transition between Chardonne and Grand Pre and a subterranean line between Hologne and Grand Pre. Besides the type of line, it is also possible to study the impact of injecting or receiving a signal on the LV side via Tpass by using the coupler connected at the same node.

The setup is also constituted of the analyses tools developed by UMONS and the measuring toolbox from Laborelec. The analyses tools developed by UMONS [2] consist in a commercially available development kit controlled by a custom software that fixes the transmission parameters (gain, modulation, packet size, transmission rate, etc.). Those modems are connected to every coupler and Tpasses shown on figure 1 excepting for the three couplers of Chardonne-Spiroux that are only used to monitor the transmission. Every transformer is equipped with a computer that controls the modems and logs the results. Each computer can be accessed remotely and are synchronized by using a 3G cellular connection and a common time server. With this tool we can obtain and analyse multiple statistical information over long periods of time. By correlating these measurements with the variation of external factors (season, temperature, noise,

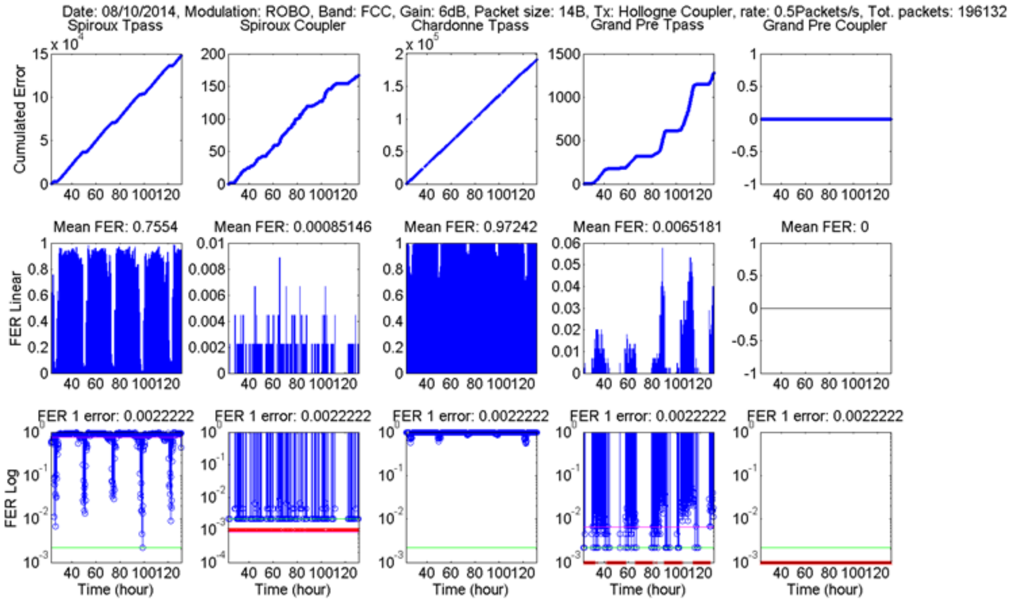

Figure 2: Summary performance for a transmission from Hollogne Coupler

etc.), it is possible to better understand the behaviour of a G3-PLC communication for the future deployment of the DSO. Moreover by using the measurement toolbox from Laborelec, it is possible to compare the variation of the performance with the evolution of the noise and its frequency content.

To take advantage of the different types of analyses that can be performed using the described setup, it was chosen to test a link every 1s. As there are 6 modems, each transmission is received by the 5 other receivers. By changing the emitting modem each second, it is possible to obtain a snapshot of the performance of 30 different communication links every 6 seconds.

RESULTS

This part presents some important results of the field trial. As explained earlier, several types of tests have been conducted. The following results will focus on the communication performance analysis on the MV line (between couplers) and the communication performance analysis from LV to MV line (crossing the transformer via a Tpass).

The first result presented on figure 2 are the global performance of a transmission test over 6 days emitted at Hollogne Coupler (end of the line) and received at every other point (coupler or Tpass). The parameters used for this transmission are ROBO mode, FCC band, maximum available Tx power (corresponding to 6dB of gain) and the smallest allowed packet size (14 Bytes). The test began October 08 2014 and finished October 13 2014. The first row presents the cumulated amount of erroneous packets, the second presents the evolution of the Frame Error Rate computed per 15min (FER) in linear value and the third row, the FER per 15min in log scale. The figure also provides the mean FER and the FER corresponding to the occurrence of one error during the computation interval of the FER (15min) for every transmission respectively above the subfigures of the second and third row. These values are also represented by a red and a green line on the subfigures of the third row. This configuration corresponds to the most robust case. On figure 2, it is possible to analyze the impact of the receiver location and the impact of crossing a transformer. First, the links using strictly the MV line (Coupler to Coupler) will be studied. The communication with the closest coupler distant of 400m (Grand Pre) yields no errors over the entire test period. By going further on the link to the farthest coupler distant of the full 2.4km of the line (Spiroux), the mean FER performance is $8 \cdot 10^{-4}$. These results demonstrate that according to the specificities of the test, communication on MV lines is possible over long distances with few or no errors.

Based on figure 2, it is also possible to analyze the performance of a communication from a MV line to the LV side (from Hollogne Coupler to Grand Pre, Chardonne and Spiroux Tpasses). By analyzing the link performance from the nearest to the farthest Tpass receiver, the results show that the mean FER varies greatly depending on the location of the receiver. A communication with the nearest Tpass (Grand-Pre Tpass) is achieved with a few losses ($6 \cdot 10^{-3}$) whereas a communication with a more distant Tpass is achieved with heavier losses ($9 \cdot 10^{-1}$ or $7 \cdot 10^{-1}$ for Chardonne and Spiroux). However, when analyzing the evolution of the FER, time intervals where the performance is much better (FER of $2 \cdot 10^{-3}$) appears between 1 and 4 a.m. As shown on figure 2, the time intervals where the FER is better seem to be cyclic. To verify this behavior, figure 3 presents the superimposition of the evolution of FER per 15min for consecutive days. These results corresponds to a transmission launched October 31 2014 and stopped November 05 2014. The transmission parameters were: ROBO mode, FCC band, average Tx power (0dB gain) and the smallest allowed packet size (14Bytes). Figure 3 clearly shows that, for the selected communication, the link behavior is cyclic. The time interval between 1 and 4 a.m. is present every day during this period and the performance during the rest of the day are similar across the different curves.

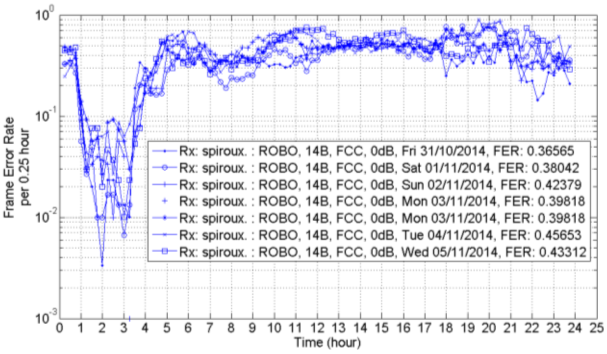

Figure 3: Comparison of FER for consecutive days

In addition to the analyses presented thus far, long term evolutions of the performance are also necessary. To be able to realize these analyses, we use the mean FER of one day as the performance indicator. The results are provided on figure 4. This figure represents the long term evolution of the mean FER per day for different communication from the LV to the MV side of the grid crossing a transformer with a Tpass. It is constructed by comparing results sharing the same configuration but made at different time. The configuration used for these test is the following: ROBO, FCC, 6dB, 14Bytes. This analysis is useful to determine if the behavior of a communication link is stable over long periods of time and to determine the overall effect of external factors such as the season. Analyzing figure 4, stable values of the mean FER are observed over time. However, slight variations are present. This behavior has to be further studied by comparing the FER variation with other external parameters such as the transfer function, the temperature, etc.

A first step to understand the variations of FER observed on the previous figures was to measure the noise present on the line during the different tests. This type of measurement is then compared with the FER variations to have a better insight on how the link performs in real-cases conditions. Figure 5 provides this kind of analysis. The first row presents the evolution of the FER per 15 min during the same period and with the same parameters as figure 4 (from 10/31/2014 to 11/05/2014 between Chardonne Tpass and Spiroux Coupler). On the third row, the spectrogram of the noise (evolution of the spectral density of the noise for a frequency range and over time) measured during the same time interval is presented. The color intensity represent the spectral density in dBμV/Hz. Finally, the second row is extracted from the spectrogram and represents the total noise power density over time in the FCC band. This final figure gives an overall indicator on the quantity of noise present on the line. By analyzing figure 5 closely, it is clear that the mean FER is influenced by the noise on the line. For instance, the best performance in terms of FER corresponds to zones on the spectrogram where the amplitude of the noise is lower. It is also possible to remark that the zone of best performance happens at the same time every day which shows a repeatable pattern as shown on the previous figures 2 and 3.

These results gives insight about the behavior of G3-PLC on MV line but are not thorough enough to ensure the usability of this technology for the practical needs of ORES. Further studies taking into account the transfer function, the power consumption on the transformers and other external parameters need to be realized.

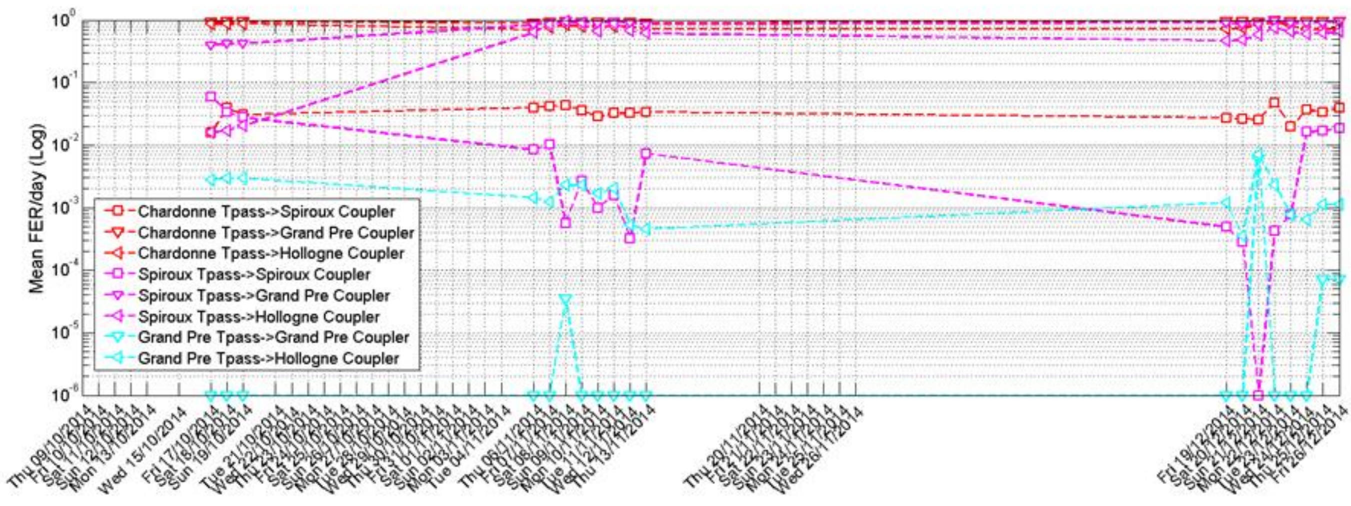

Figure 4: Evolution of FER computed per day from LV to MV side

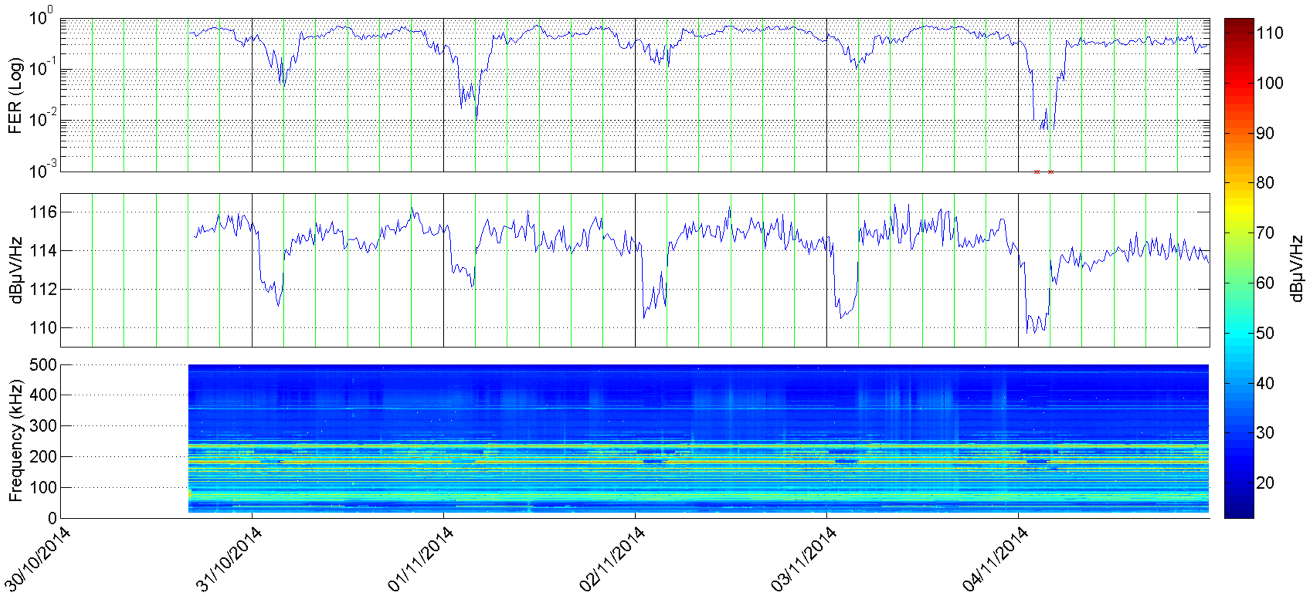

Figure 5: FER and noise comparison between Chardonne Tpass and Spiroux Coupler (Vertical line spaced by 4 hours)

CONLUSIONS AND PROSPECTS

This article described the field trial realized in Marche-en-Famenne, Belgium by a consortium formed by ORES, Nexans, Laborelec and the UMONS. The current results of this field trial show that the collaboration of every members of the consortium resulted in a functioning measurement setup capable of analyzing the performance of G3-PLC on the MV line over long periods of time. This paper shows that in the case of the considered field trial, G3-PLC communication is functional on MV lines in the FCC band. However, further steps have to be taken to study the possibilities that G3-PLC on MV lines can offer to DSOs. Indeed, for the G3-PLC to be of any practical use for ORES on MV lines, further studies are to be realized. The next steps of these analyses will be to correlate the performance with the load present at different points on the line, to further study the performance evolution over longer periods of time (seasons for instance), to take into account practical needs from ORES to better fit the test parameters with real practical telecommunication needs. Another aspect of the field trial that needs to be studied is to ensure that the parameters used for the transmission are compliant with EMC regulations. Steps to measure the electromagnetic radiation are ongoing and will be taken into account.

ACKNOWLEDGMENTS

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REFERENCE

[1] R. Jahn, D. Lemmens, S. Uytterhoeven, "*A Power Line Communication Measuring Toolbox For The Distribution Grid*", CIRED, 2011

[2] A. Van Laere, S. Bette, V. Moeyaert, "*Analysis Tool For Temporal Evolution Of Frame Error Rate Performance In Narrowband PLC*", IEEE International Symposium on Power Line Communications and its Applications, 2015

[3] ITU-T G.9903, "*Narrowband Orthogonal Frequency Division Multiplexing Power Line Communication Transceivers For G3-PlC Networks*", February 2014