Narrowband Powerline Communication Measurement and Analysis in the Low Voltage Distribution Network

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***Abstract*—Narrowband Power Line Communication technology is widely used in Smart Grids applications as a communication infrastructure for managing and controlling the electricity network. PLC is considered as a promising technology for data transmission, because it can be deployed over existing outdoor power lines with low cost and quick deployment. However, this medium is hostile to transfer high frequency communication signals. To enable this data communication in the Tunisian Low Voltage distribution network and design a reliable PLC, it is important to have a comprehensive knowledge of the channel characteristics such as noise level, impedance, and attenuation. This paper describes an experimental measurement methodology and gives analysis of results in the frequency range from 9 to 500 kHz in various sites located in Tunisia. Results show performance of PLC system on the LV distribution network. This study will be helpful to design a device for PLC applications.**

Keywords—Power Line Communication, Measurement, Narrowband Frequency, Attenuation, Impedance, Noise;

I. Introduction

PLC systems represent a key technology for the development of Smart Grid applications in the Low Voltage (LV) networks. The use of the omnipresent electric network makes the PLC a very attractive technology since it provides low installation and maintenance cost.

According to its frequency bandwidth, PLC is classified into broadband (BB) or narrowband (NB) system [1]. Broadband PLC systems operating in the high frequency band (2-30 MHz), have been widely studied and they provide up to 200 Mbps for many applications such as wired access internet and home networking [2]. The narrowband PLC (NB-PLC) systems [3], operating either in the CENELEC bands (3-148.5 kHz) in EN50065 [4] or in the FCC/ARIB bands (up to ˜500 kHz) and delivering up to 500 kbps, are used for low-data rate applications, like remote control and monitoring, data acquisition, home automation, advanced metering infrastructures (AMI), automatic meter reading (AMR) and demand response (DR).

Recently NB-PLC technology has attracted the industry and tends to be a promising way of information exchange. NB-PLC systems have been widely used for real LV applications for Smart Grids as a communication infrastructure for industrial control and home automation. However the existing power lines were originally not designed for signal transmission, but only for electricity delivery for end customer. Otherwise, NB-PLC subjects to hostile channel conditions such as the noise level, access impedance of the channel and several other parameters. Therefore, a comprehensive knowledge of these parameters when designing a communication system is required. Recent empirical measurements have been studied the impact of the noise, the impedance and the attenuation on the NB-PLC systems. The results have been discussed in the literature [5], [6], [7]. Even if many studies are available in the literature, no works have been performed on the Tunisian LV distribution network. Therefore, to understand the power line channel characteristics and to improve the reliability of NB-PLC system, an appropriate measurement procedure should be performed in different sites for LV distribution network. It is the objective of this paper to provide an overview of this specification along with experimental results showing that the PLC communication can operate on a typical topology of the LV distribution network in Tunisia. The paper is organized as follows: Section II gives an overview of the Narrowband PLC Standards, followed by measurement methodology in Section III. Experimental results obtained from measurement across different LV distribution sites in Tunisia are presented in Section IV, followed by a conclusion in Section V.

II. Overview of Narrowband PLC Standards

PLC have to be compliant with the standards and regulations for electromagnetic compatibility which specifies the frequency bands allocated for different applications. The first generation of NB-PLC standards is based on single-carrier modulations such as phase shift keying (PSK) or frequency shift keying (FSK); it offers data rates of few kilobits per second. Due to the limited bit rates provided by this generation that do not meet the requirements of the new applications, a second generation using multi-carrier modulations, mainly orthogonal frequency-division multiplexing (OFDM) modulation, have recently emerged offering higher bit rates and more robustness and flexibility that are critical to Smart Grid applications. The first systems of this generation were presented in 1999-2001[8], [9]. More recently, in 2008 and 2009, the first two technical specifications PRIME [10] and G3-PLC [11] were developed for OFDM PLC communications systems operating in NB frequencies. Both of these specifications operate in CENELEC-A band with an extension of G3-PLC to the FCC band. A detailed description and comparison of G3 and PRIME can be found in [12], their performance and field test results are reported in [13], [14]. In January 2010, to resolve the interoperability issues among the existing technologies, the G.hnem project started to develop a unified international standard for the next generation NB-PLC technology, which integrates features of G3 and PRIME and adds new features for even better performance in coverage, throughput, robustness, and reliability than found in current solutions. This specification is detailed in the ITU-T G.9902 recommendation for NB-PLC below 500 kHz [15]. Similarly, the IEEE P1901.2 [16] project is being developed to add technological advances and maintains current G3 and PRIME specifications.

III. Experimental measurement methodology

A. Identification of Measurement Sites

In the Tunisian LV distribution network, there are two major types of power lines : overhead or underground power lines. Actually, Fig.2 represents the structure of the LV electric power distribution network in Tunisia (ElKram district in Tunis, Tunisia) under study. Although the efforts of the Tunisian company of electricity and gas (STEG) to construct underground power lines, most of individual houses are still connected through overhead power lines. As Fig.2 illustrates, the overhead LV electrical lines is represented by the green areas with a length of 716 Km, the underground power line is designated by areas in red, which has a 578 Km as a length.

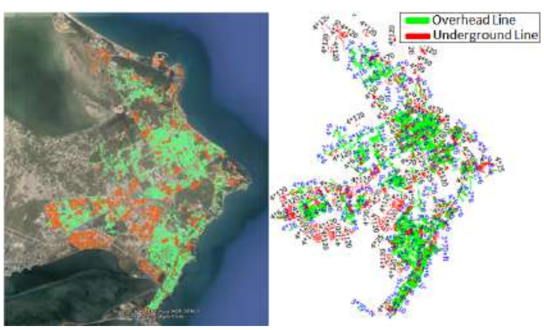

Fig. 1. Typical low voltage distribution network in Tunis, Tunisia

In order to verify that the G3 PLC communication can operate on a representative sample of the Tunisian LV distribution network, a series of measurements were performed in the two bands CENELEC-A and FCC. Measurements are conducted at three different sites chosen from the typical LV distribution network presented in Fig. 2. The first one, designed in the following scenario (S1) and illustrated in Fig. 2, is an underground network, this site is modern and simple. The second one is dense, shown in Fig. 3 and designed in the following scenario (S2), it is a mix of both underground and overhead lines; the customers in this site can be commercial or residential. The third one is illustrated in Fig. 4, designed in the following scenario (S3), it is extremely dense and complex; it is an overhead network in which all the customers are residential.

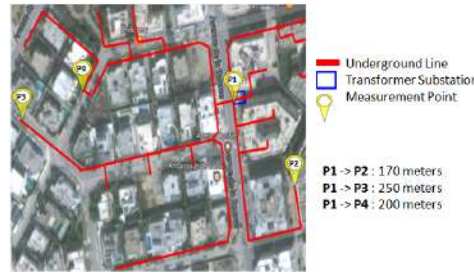

Fig. 2. Measurement site (S1): Underground Low Voltage distribution network.

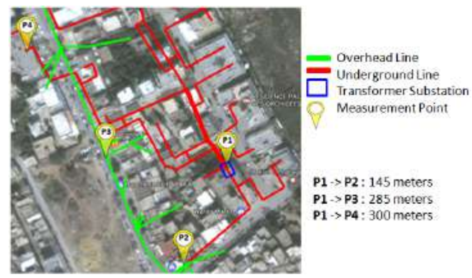

Fig. 3. Measurement site (S2): Underground and Overhead Low Voltage distribution network.

Fig. 4. Measurement site (S3): Overhead Low Voltage distribution network.

B. Experimental Procedure

The goal of the measurement is to verify that the G3 PLC communication can operate on a representative sample of the Tunisian LV distribution network. Therefore, a series of measurements was performed to get the major power line channel parameters like the noise level, the access impedance and the attenuation. The measurement setup, shown in Fig.5, consists of a measurement system connected to a coupling unit. The measurement system is composed of an analog frontend and a digital signal processing unit capable of sending and receiving signal in full duplex. The coupling unit[17]couple and decouples the high frequency signal from or to the power line. In other words, it blocks the 50/60 Hz current from entering the measurement instrument.Two systems are required to perform the measurement, the first one is installed on the LV side of a transformer substation, and the second one is connected on the LV side at different distances from the transformer.

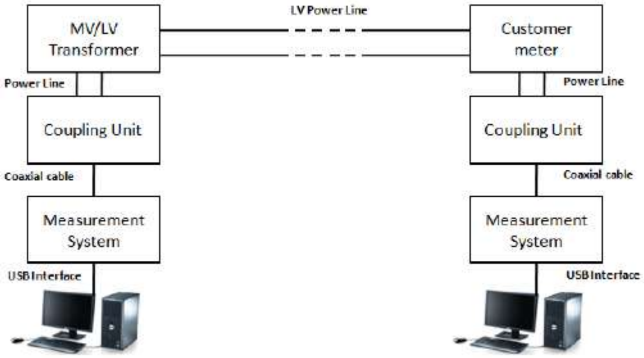

Fig. 5. Schematic diagram of measurement setup

All the measurements are controlled by a computer which is connected to the measurement system with an USB interface cable. The measurement setup is based on a line-neutral configuration in which the signal is injected differentially between one of the three phases and the neutral. The measurement is realized between two points, in the transmission point designed (P1) a sequence of a sine sweep signal in the frequency bands of interest is injected in the LV network, then in the reception point, the measurement system receive and record the injected signal. This measurement procedure is repeated for each site in three different points of reception designed (P2), (P3) and (P4) in Fig.2, Fig.3 and Fig.4. The channel parameters were measured in the two bands of interest, CENELEC-A and FCC at different times of the day.

IV. Analysis and results

A. Noise

PLC channel suffers from several kinds of disturbances which are defined as the stationary noise and the impulsive noise. This noise is caused by the users connected to the power grid and to external signals. Therefore, measuring and analyzing the noise present in the PLC channel is a key step to characterize the PLC system. Recent empirical results on PLC noise measurements have been reported in [6], they show that the noise is periodic and cyclostationary.

A spectrogram of noise and a time-domain noise trace measured in the three typical urban sites (S1), (S2), and (S3) are given respectively in Fig. 6, Fig. 7 and Fig. 8. Each Figure illustrates the time and frequency domain analysis of the noise observed at each site, the top plot corresponds to the spectrogram of noise and the bottom plot shows the time-domain noise.

Fig 6 shows that the site (S1) has two high-level of noise power, they are around 70 and 125 kHz which occur every T. The time domain noise shows bursts of impulse noise occurring every 10 ms, while the bursts themselves are around 8 ms wide. The amplitude of the noise waveform reaches only a value of about 0.4 V.

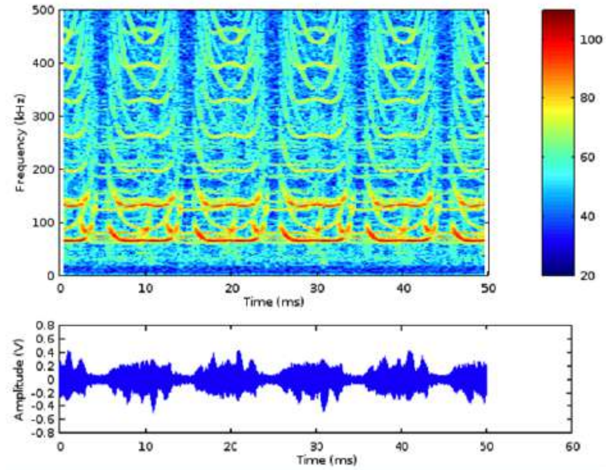

Fig. 6. Measured noise and its corresponding spectrogram in (S1)

Fig. 7 shows the measured noise in the second site (S2), it illustrates that most of the energy in the noise is concentrated between the frequencies 50 kHz and 100 KHz, the noise level is practically constant. In the time domain plot it is seen also that the noise has bursts of impulse noise which occur every 10 ms but the wide of the bursts in this site is around 2ms. Here the amplitude is about 2 V. The noise level is explained by the presence of commercial and industrial customers in this site.

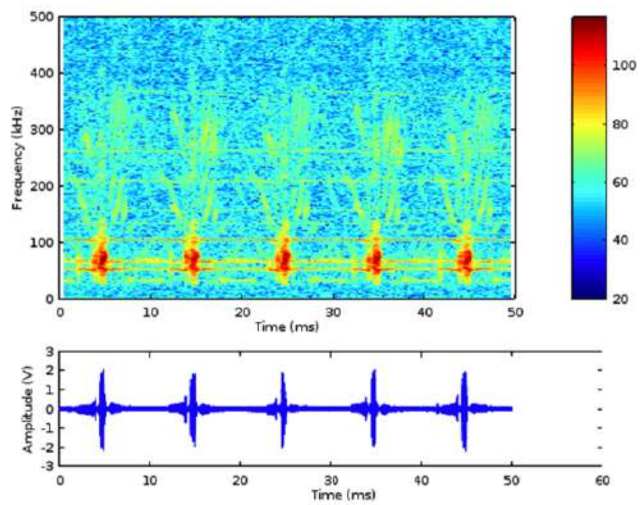

Fig. 7. Measured noise and its corresponding spectrogram in (S2)

Fig. 8 shows that the site (S3) has the worst noise because the network is very complex and extremely dense. It is observable that the impulsive term of the noise is not very clear and the power level is around the frequencies 60, 120, 220 and 380 kHz. The cyclostationarity of the noise is always observable in the time domain plot, hence bursts of impulse noise appear each 10 ms and the overall duration is about 1ms, the level of amplitude reaches a value of about 0.2 V.

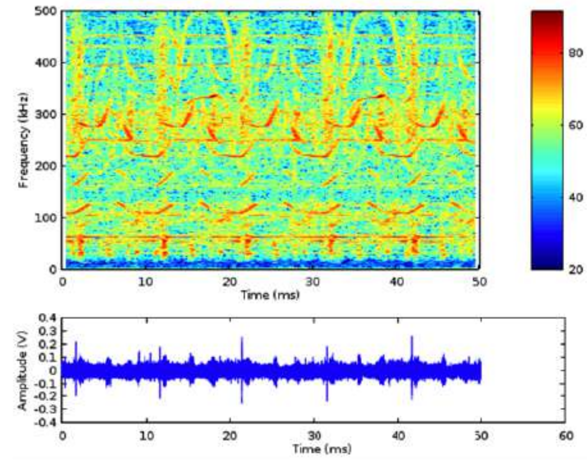

Fig. 8. Measured noise and its corresponding spectrogram in (S3)

The main observation from the measurement results of the noise at various sites is that the noise is impulsive and cyclostationarity with the same period as the zero crossing of the mains AC cycle ($T = \frac{T_{AC}}{2} = 10ms$). In addition, there is a higher concentration of noise power in the lower frequency band with a short time-domain bursts occurring every T. This is caused by the electrical devices connected to the power grid which generate noise synchronously to the instantaneous value of the mains voltage. Otherwise, switching devices turn on and off, cause impulses synchronous to the mains voltage.

It is also observable that the power of the noise varies from site to site but the noise level at any given site is broadly constant, except for the occasional appearance of narrowband interferers caused by the loads connected in the network.This may be explained by the presence of signals coupled to the power lines radiation or via conduction which can be defined as the background noise. Hence, we note that the noise is a mixture of impulsive noise and background noise.

Comparing the noise in the three different sites, we can say that the noise in the site (S3) is higher than the noise in the sites (S1) and (S2). This is explained by the increasing usage of electrical appliances in this site and the high number of customers which are connected to the grid at the same time. In fact, Noise level heavily depends on loads' profiles and the density of interconnections. Hence, noise level is important in sites with complex topology and high loads density.

B. Impedance

Impedance is an important parameter when designing the PLC system; it is a key aspect for power line modem development. Therefore, for the optimum modem design, power line impedance must be known. To determine the value of the impedance in the three sites of the LV distribution network under study, many data are measured in different point and at different time in the CENELEC and FCC band.

The measured impedance for the site (S1), shown in Fig. 9, are found to be from 4 to 7 Ohms at the CENELEC-A and from 7.9 to 17.5 Ohms at the FCC band.

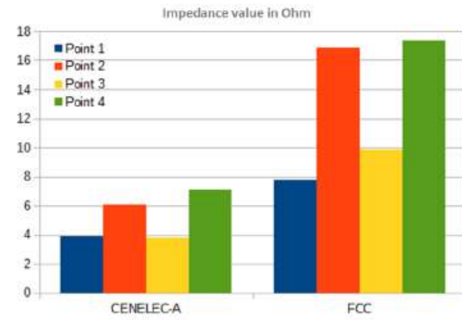

Fig. 9. Measurement results of the impedance in site (S1)

The values of impedance recorded on the site (S2), illustrared in Fig. 10, are observed between 2 and 5.5 Ohms in the CENELEC-A band, and increase at the FCC band for values between 4.9 and 24 Ohms.

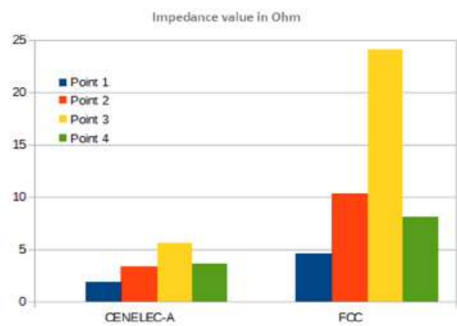

Fig. 10. Measurement results of the impedance in site (S2)

The obtained results of the impedance in the site (S3), shown in Fig.11, are between 4.8-10 ohms at the CENELEC-A band, and varies from 9 to 36 Ohms at the FCC band.

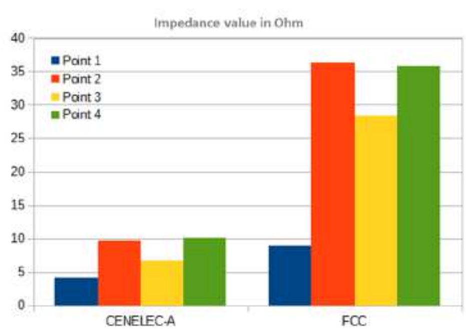

Fig. 11. Measurement results of the impedance in site (S3)

In all measurements it is observable that the impedance varies from 2 Ohms up to 10 Ohms in the CENELEC-A band and increases significantly in the FCC band but remains at acceptable levels and does not exceed 36 Ohms.

The impedance is especially low at the substation transformer and changes from point to point. This is due to the high number of consumers connected to transformer substation at the same time. Impedance changes from point to point because loads which are connected and disconnected to power lines vary from consumers to another. Results of the impedance are quite comparable to the measurements results obtained in a recent empirical study reported in [18].

Variations on the impedances can be explained by the variations of the loads which are supplied from the main voltage. In fact, the impedance strongly depends on the number of loads connected at the same time on the power line, because when the energy usage is high, more devices are connected to the grid and hence the impedance is low and when the power line is empty the impedance is high since the energy usage is low.

The exact behavior of the impedance is not predictable and depends mainly on the ensemble of loads connected to the grid and the distribution transformers; it can be quite different from site to site as it is shown by the measurements.

C. Attenuation

To analyze the PLC over the LV distribution network measurement of the attenuation in different point of the grid were performed in the CENELEC-A and FCC bands. All measurements are in both directions (e.g. from the substation transformer (P1) to measurement point (P2) and vice versa). Additional tests were performed at night (during peak loads) in the site (S3) to see the possible impact on CPL system.

The attenuation is calculated from the injected signal transmitted by the measurement system and the received signal at the measurement point. Based on the calculated data of attenuation and the recorded noise level the signal-to-noise ratio (SNR) is obtained. This parameter allows better understanding the behavior of the PLC channel and estimating the performance of the communication system, in fact the communication is good when the SNR is higher. Fig. 12 shows the variation of the SNR with frequency and distance in site (S1).

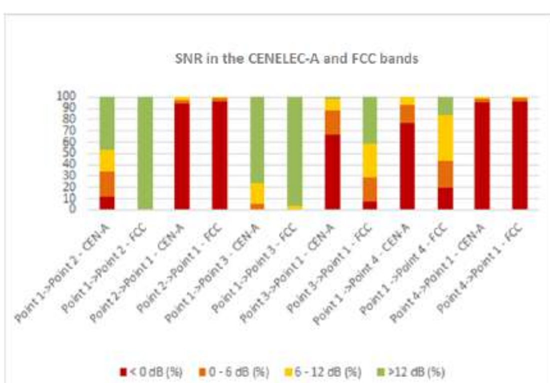

Fig. 12. Comparison of SNR in the CENELEC-A and FCC band in site (S1)

A clear asymmetry of communication is observed, the SNR from the transformer to the received points is much better than the reverse. The topology of the network can explain this asymmetry, in fact (S1) have a "Star" structure; many departures from the transformer point (P1) with great distance to reach the first point, thus the load at point (P1) is very high and the impedance is low which limits the input signal.

Fig. 13 shows the obtained SNR in site (S2).

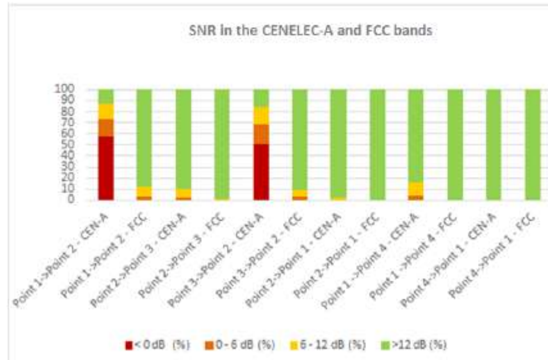

Fig. 13. Comparison of SNR in the CENELEC-A and FCC band in site (S2)

The communication between the point (P1) and the point (P2) on the CENELEC-A is operating at the limit. These difficulties of communication towards point (P2) in CENELEC-A band are mainly due to noise. The communication with the point (P4) is functional despite a large distance (underground) 300 m, this is due to low load and high impedance in this point.

Fig. 14 shows the SNR in the site (S3).

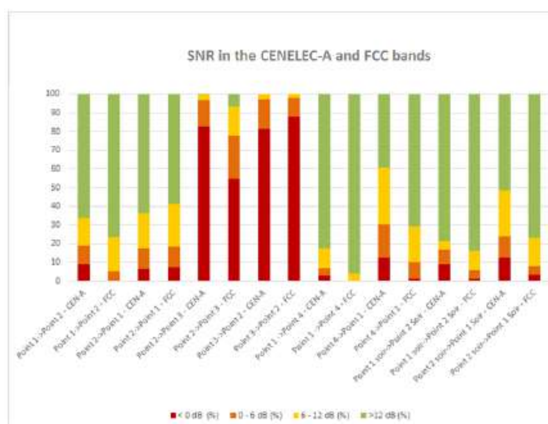

Fig. 14. Comparison of SNR in the CENELEC-A and FCC band in site (S3)

It is observable that the PLC communication on this site (S3) is functional. However, the significant attenuation (due to the load) leads to distances per weak link. The density of the network will ensure the availability of the repeated points. It can be observed that the difference between day and night does not have a significant impact on the quality of PLC system concerning attenuation and noise.

The main observation from the measurement results is that the SNR in the FCC band appears to be better than the SNR in the CENELEC-A band, moreover it is noted that the overall SNR in the measurement sites are higher expect in some point where the receiver is far away from the transmitter and the level of the noise is high at this point.

As a conclusion, we can say that the signal-to-noise ratio (SNR) at the receiver point can be very low if the transmitter is far away while a large noise source can be nearby. This is reasonable since the SNR depends strongly on the distance between the transmitter and the receiver and the noise level.

V. Conclusion

In this paper, new empirical data on the noise, impedance and attenuation of the LV distribution network in Tunisia are presented. The possibility of communication in two ways has been investigated. The obtained results show well differing profiles of noise, impedances and attenuation. The highest performance is achieved in sites (S1) and (S2) the lowest one is in site (S3). The noise level and attenuation in the site (S3) is very high. Therefore, communication in complex and dense topology is very risky. The attenuation and impedance are quite typical and have better performance in the FCC band than in the CENELEC-A band (higher impedance, less attenuation). It is also noted that the SNR appears to be better in the FCC band than in the CENELEC-A band.

Overall on the three sites the results are quite comparable to what is obtained in other countries. These results may be taken into consideration used in PLC system design. Moreover, experimental studies like this one must be repeated in various countries or parts in the world to facilitate designing the true and standard system for general use worldwide.

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