Evaluation of Noise Effects on Power Line Communication in a Narrow and Wide Band Frequency Spectrum: A case study of Electricity Distribution Network of Ghana

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***Abstract* - Power Line Communication (PLC) is a means of communication that uses the power line network medium to transmit data and signals. The PLC system is basically divided into Narrowband and Broadband PLC system. The PLC is considered to be one of the most favourable candidates for Advanced Metering Infrastructure (AMI). In the past Electricity Company of Ghana (ECG) used PLC (Narrowband-PLC) as a medium of Communication for smart prepaid metering but was unsuccessful due to hostile nature of the power line characteristics like electrical noise and interferences. Noise characterization of the power lines channel is very important for PLC systems design. In this paper, the measurements of noise properties injected by various loads in the Narrowband frequency 1-500 KHz and Broadband frequency 2-12 MHz spectrum are presented and discussed. The outcome of the study suggests that the Narrowband frequency region 1 - 500 KHz is marked with noise and therefore noise will have a negative impact on PLC categories operating under this region of frequency band. On the other hand, noise level on the Broadband frequency region 2-12 MHz was found to be minimal and therefore noise will have very little or no impact on the PLC Category operating under the Broadband frequency band (BB-PLC).**

Keywords - Power Line Communication, Advanced Metering Infrastructure, Frequency Spectrum, Broadband-PLC, -Narrowband-PLC, Smart grid.

I. INTRODUCTION

Smart metering is an essential part of Smart grid that embraces emerging communication technologies among meters, central devices and objects in the Internet of Things (IoT). Smart metering makes use of normal electricity meters which are empowered with communication devices enabling communication between service provider and customers. This form of communication allows the service providers to monitor the customer remotely and attend to maintenance and safety needs. On the other hand, the customer may purchase electricity unit online, check his balance and performs a number of activities.

Power Line Communication (PLC) technology enables transmission of information and signals through existing power lines purposely intended for electric energy transmission and distribution. The PLC designates a technology that uses the medium and low voltage electrical network to provide telecommunication services [1]. Communication over medium-voltage and high-voltage transmission lines became popular in the 1920s [2], [3]. The first PLC patent on a power line signalling electricity meter was applied by Joseph Routine in UK. In 1950, the first PLC systems, known as Ripple Control, were designed and then deployed over medium- and low-voltage electrical networks, [1]. Even with its relatively long history, PLC was not widely applied due to signal attenuation and severe noise until breakthroughs were realized in the twenty-first century. The PLC technologies were primarily used for supervisory, and protection of electric power networks. Utility companies across the world have been using PLCs for decades for remote metering and load control applications, [4]–[6]. The PLC technology is now applied in more fields such as smart grid, industrial control, Internet of Things (IoT).

PLC allows significant reduction of communication system cost and reduce the wiring complexity of smart meters. The PLC technology is further perceived as an important means of cutting down or minimizing power losses and optimizing

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operation revenue. The Advanced Metering Infrastructure (AMI) communication system, supports various communication technologies, namely GPRS, Infrared and Power Line Communication (PLC). Among these various communication techniques, PLC is noted to have inherent benefits, like wide coverage (available as long as there is a grid), reduced operation and maintenance (O&M) costs.

PLC is usually deployed in narrowband and or broadband modes based on the operating frequency and transmission rate of signals on the power lines. The Narrowband Power Line Communication (NB-PLC) transmission operates with frequencies up to 500 kHz. This is in opposition to the Broadband PLC (B-PLC) that operates with higher bandwidth at shorter distances with a much higher frequency band. CENELEC standardization body in Europe, has recognised the 148.5 kHz frequency for use in NB-PLC systems in public utility's power systems. Communication results obtained with this frequency are acceptable, ranging from 10 Kbps to 100 Kbps. These rates are suitable for telemetry and control applications. In other countries like North America, Japan and China, the frequency range of up to 500 kHz are for NB-PLC and offers a reasonably wide communications bandwidth (up to above 300 Kbps).

However, PLC faces numerous challenges, the most prominent being the interference and noise induced by neighbouring signals on the power line. The power line medium is characterized by several challenges such as high channel attenuation, capacitive and inductive coupling, electromagnetic noise and perturbations level on the electrical power lines owing to the presence of various electrical loads. These characteristics haphazardly affect the performance of the PLC [7]–[9]. Noise on the power network can cause undying variation of the voltage curve [10], [11].

[12] described in details an integrative description of PLC noise disturbances. According to their work noise, disturbances were classified into five (5) types based on their intensity, time duration, source, and spectrum band. Figure 1 clearly illustrates the combination of these noises which gives rise to the effective noise disturbance of the channel, [12]–[15]

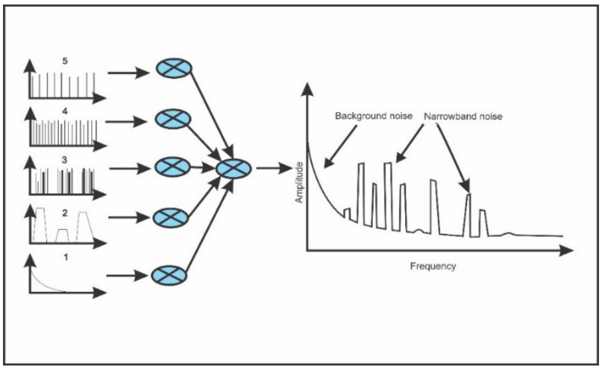

Fig. 1. Combined Noise Disturbances in PLC Systems.

Legend

1. Colored background noise: It is a thermal Gaussian noise and it can be approximated by several white noise. It is produced by electrical devices such as pumps, microwaves etc.
2. Narrowband noise consists of modulated sinusoids, originated from broadcast radio stations operating in high frequencies.
3. Impulsive noise is classified into aperiodic and periodic noise. Aperiodic noise is generated by transient switching gears and periodic noise are generated by rectifying diodes etc.
4. Harmonic noise is made up of many frequencies used by a group of devices
5. Asynchronous impulsive noise which results from switching transient circuits in the networks. This noise has the most pronounced effect on digital data communication over PLC due to its high power spectral density (up to 50 dB) [16].

Besides the noise challenges, PLC technology has been used intensively for Advanced Metering Infrastructure (AMI). AMI is an automated system that allows two-way communication between a smart utility meter with any device provided with IP address. AMI is used by the utility companies to provide real-time data on power consumption and allow customers to make informed decisions on energy usage considering price at the time of use. The Advanced Metering Infrastructure communication network requires the use of a number of advanced technologies to be effective. One of the primary prerequisites is a reliable bi-directional communication network. The basic AMI communication network setup requires smart and reliable transmission medium to deliver constant network connectivity from the smart meters (SM) to the aggregation nodes and data uplink to the AMI control centre. Typically, the full setup of the AMI system includes smart meters (SM), Data Concentrator Units (DCU), communication medium, management system for data, and then interface application platform.

Despite the availability of numerous studies on the PLC globally, no feasibility studies have been conducted with the Electricity Distribution Network in Ghana to confirm the usability of the PLC technology. Previous efforts were made earlier with the attempt to implement the NB-PLC but they quickly failed due to lack of study on noise profile on the power line network and deployment of noise mitigation techniques. The need to integrate PLC in Smart Metering in Ghana is still crucial and becomes a serious handicap in carrying forward the progression of smart grid adoption in Ghana.

In this paper, a comprehensive analysis of NB-PLC and BB-PLC has been conducted and documented using real experiments to investigate the feasibility of PLC system as an integral part of AMI communication systems. Specifically, the study is geared towards the measurements of noise injected by various load in the Narrowband frequency (1 – 500 KHz) and Broadband frequency (2-12 MHz) on carefully selected sites. The outcomes of this study are vital in planning a reliable and efficient PLC system in a low voltage power distribution network in Ghana. The rest of the paper is structured as follow: Part 2 deals with the methodology, part 3 presents the results, part 4 deals with the discussion and finally part 5 presents the conclusion.

II. Methodology

This paper is concerned with the third order intercept of a dual tone input signal for which all the frequency of FM stations in Accra have been fed to the intermodulation analysis software. Results indicated the number of hits and the same assessment was reconducted in some few cases using Matlab software that led to the plotting of power density graphs. This section presents a brief mathematical approach to estimating the noise induced on a PLC followed by a description of the experiment conducted.

A. *PLC Noise Estimation*

Noise in the PLC channel can be modeled as a cyclostationary process and its amplitude distribution can be modeled as Gaussian distribution. The variance of noise affecting a PLC channel is assumed to be the sum of three types of noise and it can be expressed as follows ;

$$\sigma_{PLC}^2 = \sum_{i=1}^{3} A_i[(2\pi ft + \theta_i)]^{n_i} \quad , \qquad (1)$$

Where $f = \frac{1}{T}$ is the frequency of the AC voltage, typically 50 or 60 Hz. A_i is the parameter of amplitude, θ_i is the parameter of phase and n_i is the parameter for degree of impulsiveness. Equation (1) comprises three types of noise; stationary noise (i = 1), cyclical continuous noise (i = 2), and cyclical impulsive noise (i = 3). The first category is a time invariant noise component, thus parameters θ_1 and n_1 have no meaning. The second and third categories are the periodic noise components. Experimental values of these parameters extracted from previous literatures is presented in Table 1.

Table 1. Parameters identifying the variance of noise affecting a PLC channel

Parameters	A_1	A_2	n_2	θ_2	A_3	n_3	θ_3
Environment A	0.13	2.8	9.3	128°	16	5.3	161°
Environment B	0.7	0.22	5.3	100°	30	1.5	174°

A number of algorithms have been proposed in literature for the estimation of the variance. Some are derived from the estimation of noise based on higher order statistics while others are based on the Maximum-Likelihood estimation principle.

B. *Experiment Description*

This paper is concerned with a technical assessment of noise properties on Low Voltage Power lines for frequencies between 1 – 500 KHz in the Narrowband and 2- 12 MHz in the Broadband. Three different locations have been used to compare the noise variations in the two frequency bands. The experimental setup is shown in Figure 3 and comprises a network diagnostic instrument connected to a laptop computer equipped with Hi-Studio software and a coupler enabling the interfacing of the instruments with a 220 V, 50 Hz power line.

Huawei BB-PLC was the physical simulator used for this study and has excellent features. Huawei BB-PLC Communication Solution is designed for AMI functions and provides high-speed, reliable, and real-time long-distance communication. Huawei BB-PLC Communication Solution creates a power line communication channel transmission model that can select the best signal transmission frequency. In addition, the solution obtains the characteristics of power line communication channels, such as signal attenuation, impedance, and noise. Accordingly, the solution provides effective anti-noise and anti-attenuation technologies, greatly improving power line communication performance and realizing high-speed, reliable, and real-time long-distance communication. OFDM is the basis of Huawei Broadband PLC physical-layer technologies. Orthogonal Frequency-division Multiplexing (OFDM) implements physical-layer communication by integrating anti-noise and anti-attenuation technologies. OFDM technology has the advantages of high spectrum utilization, strong anti-noise and anti-channel fading capabilities and strong capability in resisting ISI (Inter Symbol Interference)

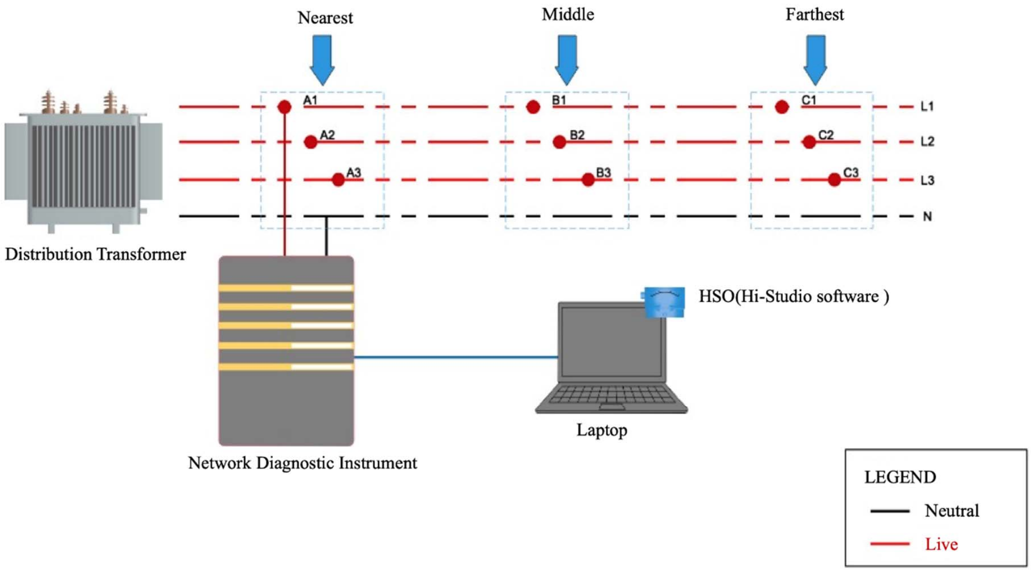

Fig. 1. Noise test setup

Fig. 2 Huawei Network Diagnostic Instrument

The power line channel measurements have been conducted for bandwidth within 1 KHz – 20 MHz The network diagnostic instrument designed by Huawei Technologies is attached directly to the low voltage grid (phase to neutral). The network diagnostic instrument is directly connected to the 230V low voltage phase to neutral and the Hi-Studio application was run on a laptop and the noise data was characterized by captures, with the signal output from the network diagnostics instrument. The resultant signal is captured by the Hi-Studio software which also provides the noise profile. The experiment has been repeated severally under the same conditions for the two frequency bands and the obtained graphs have been recorded for analysis. The three phases of the supply have been tested individually for a period of 30s each, since the diagnostic instrument can only measure a single phase.

Before conducting the noise test on the power line, it was ensured that no artificial signal resource was present in the same environment. The measurements were conducted by determining the total power of noise signals that occupy the 1 – 500 KHz narrowband frequencies and 2- 12 MHz broadband frequencies. The test was conducted in two different environments including industrial and residential areas.

For each scenario, the experiment was done close to a distribution transformer that supplies a considerable number of users to ensure constant power delivery. Secondly, the experiment was also conducted closed to a feeder at a distance from the distribution transformer. Thirdly, a position far from both the distribution transformer and the feeder was also considered to collect noise data. Noise data for supply lines L1, L2 and L3 were collected in each position so there are different graphs obtained for all scenarios.

IV. Results

The following seven graphs present the noise profile obtained for phases L1, L2 and L3 respectively for each of the three positions adopted for measurement namely: a) At approximately 50 meters close to a distribution transformer, b) at approximately 400 meters close to a distribution feeder located at a considerable distance from a distribution transformer and finally c) a location far distant of about 700 meters from both the distribution transformer and feeder.

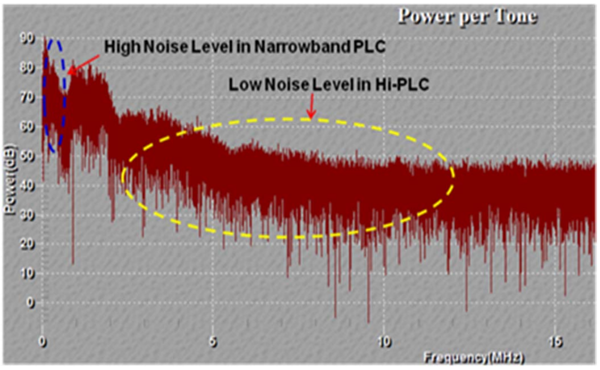

Fig. 3. Noise distribution on the low voltage power line in Industrial Area Phase 2 point 1

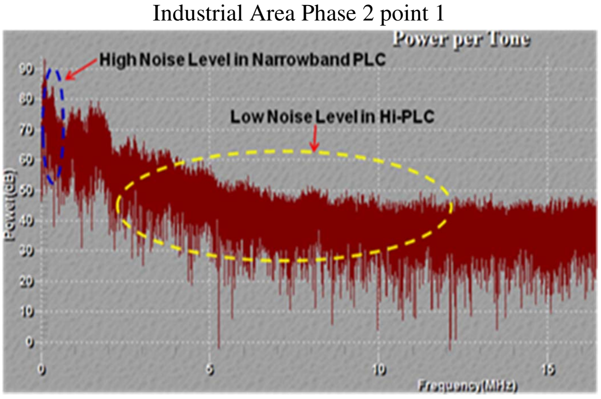

Fig 4 Noise distribution on the low voltage power line in industrial Area Phase 2 point 3

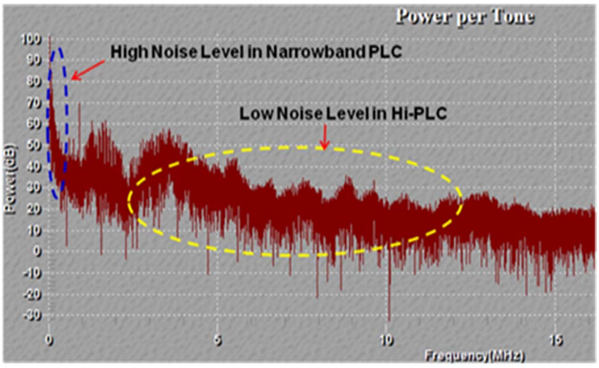

Fig. 5. Noise distribution on the low voltage power line in Industrial Area Phase 2 point 3

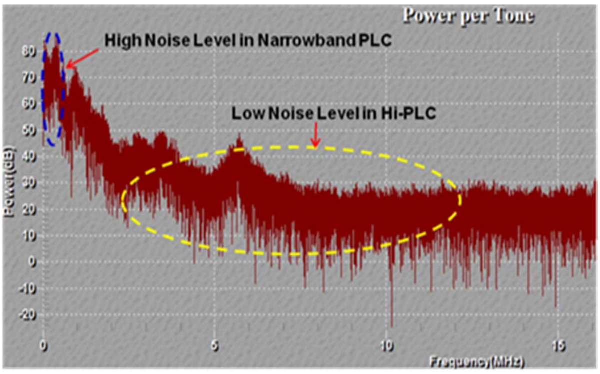

Fig. 6. Noise distribution on the low voltage power line in Residential Area Phase 1 point 1

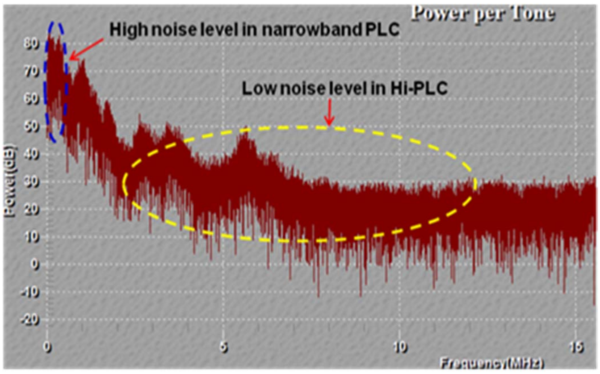

Fig. 7. Noise distribution on the low voltage power line in Residential Area Phase 2 point 2

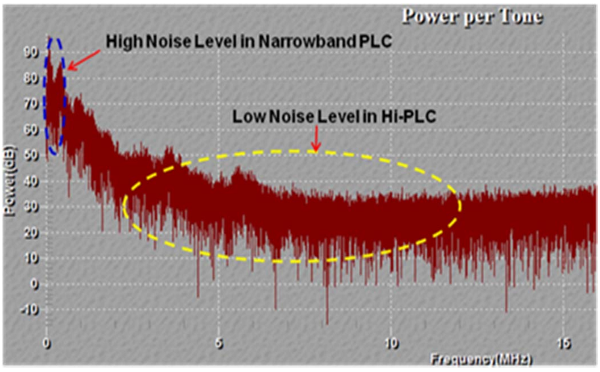

Fig. 8. Noise distribution on the low voltage power line in Residential Area Phase 2 point 3

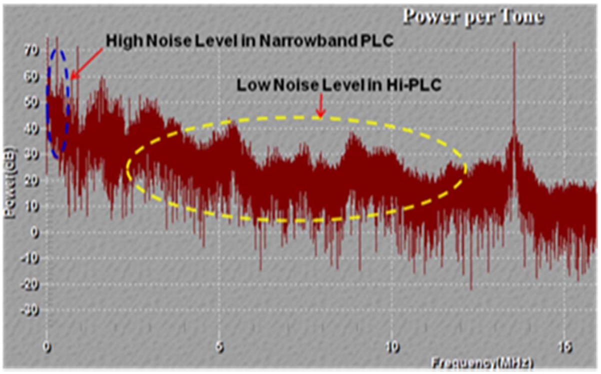

Fig. 9. Noise distribution on the low voltage power line in Area with newly stringed power lines Phase 2 point 3

The noise results between the narrowband and the broadband PLC were compared and analysed. In general, the industrial and residential areas exhibited similar noise characteristics within the given range of frequencies. The noise statistics remain the same within the 30 seconds period of test except minor variations.

Referring to the graphs above, it can be observed that the noise level on the narrowband spectrum is seen to be more profound as compare to broadband spectrum. Noise is considered to be unwanted signal that exist in the communication medium. This unwanted signal arises from variety of source. Man-made noise such as 50 Hz supplies and harmonics, switch mode power supplies, thyristor circuits and many others. Flicker noises or low frequency noise are produced by active devices, integrated circuit, diode, transistors etc. The existence of this unwanted signal cannot be practically avoided in a communication system. In reference to the results, the high noise level on the narrowband will limit or make data transmission unreliable. The broadband frequency band exhibit lower noise level as compared to the narrowband. A good transmission medium is characterized by a low level of noise. However, considering the fact that high frequency signal attenuate faster than lower frequency signals, it was observed that the signal levels narrow down slightly uniformly as the frequency increases indicating the presence of attenuation due to the resistance, inductance, and capacitance of the power line. Additionally, a good transmission in the broadband range of frequency should be characterized by a uniform level of attenuation across the frequency spectrum (2-12 MHz). Since the signal level exhibits a uniform attenuation in the case of this experiment, an amplifier can therefore be used to boost the signal level. On the other hand, if a transmission medium exhibits a non-uniform attenuation, the amplifier will need to amplify certain sections of the signal differently from the other sections leading to high cost in the amplification.

The obtained graphs demonstrate that noise levels on the power line vary under each scenario with the industrial area recording the highest noise level. The measurements show that the noise level decays with increasing frequency and is especially high in the narrowband frequency spectrum. The summary of the findings is stated below

- The noise energy injected by various loads is mostly concentrated in the narrowband frequency (1 – 500 KHz) and decrease with increasing frequency.
- The noise energy injected by various loads in the broadband frequency (2 – 12 MHz) was significantly lower compared to the narrowband frequency (1-500 KHz).
- The noise on the power lines was observed to be frequency selective with concentration on the narrowband spectrum.
- The noise energy at any given scenario was broadly constant , except with the occurrence of occasional narrowband interference
- The BB-PLC Bandwidth results showed that a guaranteed Quality of Service (QoS) is required for the AMI application.
- It was also found that the NB-PLC attenuation at frequencies below 500 kHz were comparatively lower than the values obtained at higher frequencies, thereby allowing narrowband standard to reach longer distances than their broadband counterpart. This finding agrees with previous literature on the same subject including [17], [18].

V. DISCUSSION

As proven by the test experiment, the Power line medium is unfavorable environment and its characteristics tend to fluctuate in time, site and with varying power loads. Mostly the loads that generates noise are found in the low voltage networks. Part of the design goal of a power line network physical characteristics should be the minimization of unwanted signals.

Using power lines medium for communication purpose requires refined modulation schemes. Conventional modulation techniques such as ASK, PSK or FSK are normally ruled out by the hostile behavior of the power line. Hooijen presented a comprehensive examination on the performance of numerous modulation and coding methods on the Residential Power Line Carrier (RPLC) channel [19], [20] and found that most of the conventional modulation scheme listed above are inadequate to meet the stringent quality requirement of PLC channels. Furthermore, [13] presented the characteristics of power line channel and their effect on communication system design.

The choice of ideal frequency that is not prone to interference by various sources of noise that limit data transmission on the power line is a primary step towards minimizing interference on the PLC system. Lars (1999) presented a modulation method that could possibly become a candidate in PLC.

Most of the PLC technology adopts OFDM (orthogonal frequency division multiplexing). The OFDM enables distribution of data information over a huge number of carriers at defined frequencies. The orthogonality in these carriers avoids interference such as RF and multi-path distortion, generating high spectral efficiency [8], [14], [15].

VI. Conclusion

This paper presented noise characteristics injected by various loads on various power line communications (PLC) technology frequency bands (1-500 KHz & 2 – 12 MHz) on the power line transmission network based on the field test conducted in Ghana. The noise energy was observed to be concentrated on the narrowband range and decreases with increasing frequency. Subsequently, this influences the reliable communication of high-speed data on power. The effects are more felt in the narrowband range than the broadband range. It therefore inappropriate to use the frequency range of 1-500 KHz for effective communication on the low voltage power line network. The narrowband frequencies are not suitable for reliable data communication on power lines. The frequency ranges of 2MHz -12 MHz, attributed to the broadband is more suitable for the power line networks. Additionally, the paper suggested some noise mitigation techniques that were based on the use of OFDM based modulation schemes rather than the conventional techniques used for digital data transmission.

This study confirms that Broadband PLC is more immune to noise than Narrowband PLC communication and the adoption of OFDM based modulation scheme is the way to improve efficiency in Broadband PLC communications.

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