

Effect of Non-Optimal Amplitude Frequency Response on Transmission of Power Line Communication Signals

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Abstract
Power line Communication (PLC) systems represent a relatively recent and rapidly evolving technology, aimed at the utilization of the electricity power lines for the transmission of data. This is due to increasing demand of low cost telecommunication, broadband and access to internet services. Power lines are inherently the most attractive medium for home networking due to its universal existence in homes, the abundance of alternating current outlets and the simplicity of the power plug. This work presented the effect of non-optimal amplitude frequency on transmission of power line communication signals by utilizing Orthogonal Frequency Division Multiplexing (OFDM) system. The simulation was carried out using MATLAB/SIMULINK with additive white Gaussian noise (AWGN) in order to obtain correct simulation performance results. Two channels of PLC were considered, the worse channel was taken into account and the channel output signal power was obtained. Bit Error Rate (BER) of Binary Phase Shift Keying (BPSK) in conjunction with multipath channel was used for a comparative performance of the studies. The results indicated that data transmission in PLC environment needed a signal to be amplified or transmitted at higher powers. The result also showed that non-optimal amplitude frequency response had no effect on transmission of the PLC signal in the frequency bands despite the low noise signal in the system. The result demonstrated that OFDM exhibited better BER performance for providing adequate transmission channel for information over a PLC system. This approach provided accurate reliability, security and robustness for better management of available energy resources to overcome the limitations of existing Power line communication technology.
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I. Introduction

Power Line Communication (PLC) is a way of transferring information or data through an electrical power line to provide high-speed communication capabilities to end users. Electric power lines offer a tremendous potential for extended fast and reliable communication services [3]. PLC provides various fields of applications such as simple inexpensive services embodied into household appliances, where data rates of only several kilobits per second or less are sufficient. In addition, internet access via the wall socket, where data transfer speed is in the lower megabit range up to high-speed networking that includes fast internet access, voice over Internet Protocol (IP), and home entertainment [1, 5, 9].

In PLC systems, the electric power line is used for both energy transmission and as a medium for data communication [4]. The benefits of implementing PLC on existing electrical power line are significant, starting from the fact that there is no need for new infrastructure, which is both time consuming and expensive to install and also, no new wires are required. The advantage of using electric power lines as the data transmission medium is that it allows the end users to utilize their already existing electrical wiring systems to connect home appliances to each other and to the internet. Home networks utilizing this networking technology are able to control any home appliance plug into the AC outlet [2, 6, 8].

PLC can be broadly viewed as narrowband or broadband. In a narrowband PLC, a narrow and power line communications began after electrical power supply became widespread. The narrowband PLC is carried out through a single-carrier modulation. While broadband PLC is the use of PLC technology to provide broadband internet access through ordinary power line. Broadband PLC uses frequencies which are part of radio spectrum allocated to over-the-air communication [7, 10].

PLC systems have long being a favorite at many electric utility industries because it allows them to reliably move data over an infrastructure that they control. Interest in this application has grown substantially because there is a growing demand in obtaining up to the minute data from all metered points in order to control and operate the system. PLC is one of the technologies being used in Advanced Metering Infrastructures (AMI) systems [3].

In addition, PLC can be classified as PLC over AC lines and PLC over DC lines. PLC over AC lines is the most common form of power line communication since power is being generally transmitted via AC and not DC. All transmission lines are geared towards AC as the main focus of most companies. Whilst most companies are currently geared towards providing AC-PLC solutions, PLC in DC lines also has applications. PLC over DC lines find its applications most in renewable energy where power is generated in DC before converted to AC. It also finds great applications in transportation (electronic controls in airlines, automobiles and trains) [1, 3].

The development of appropriate PLC systems turns out to be a severe challenge for the communication engineers having to deal with very unusual channels that were neither designed, nor intended for signal transmission at high frequencies. The development of power line communication systems requires detailed knowledge of the channel properties, such as transfer function, interference scenario, and channel capacity in order to choose suitable transmission methods.

II. Power Line Signal Modulation Techniques

PLC signal modulation is a technique that enables an information signal to be transferred by changing the characteristics of an electric signal carrier. Modulation is used for both analog and digital information. In the case of analog information, the carrier is affected continuously. while in the digital information, the carrier is affected in a step-by-step fashion. The operational unit in a communication system performing modulation and the corresponding demodulation is called a modem. In analog transmission of information, both amplitude modulation and frequency modulation are used [6, 10, 13].

A. Amplitude Modulation

Amplitude Modulation (AM) is the simplest form of modulation. In this modulation, the amplitude of the carrier wave is varied in accordance with the voltage characteristic of the modulating signal. Mathematically, an AM signal can be represented as [14]:

$$S(t) = A_C[1 + m(t)]Cos\omega_C t \quad (1)$$

where, $m(t)$ is the modulating signal, ω_C is the carrier frequency, and A_C is the amplitude constant.

Amplitude modulation is used to transmit analog voice from 300Hz up to 3,400 Hz modulated on radio frequencies around 450 MHz in the mobile radio system and to transmit TV images in cable TV networks. The bandwidth of an AM signal is twice the bandwidth of the modulating signal. This is because amplitude modulation results in two sidebands on either side of the carrier frequency. The frequencies above the carrier frequency constitute the upper sideband, and frequencies below constitute the lower sideband [4].

B. Frequency Modulation and Phase Modulation

Frequency Modulation (FM) is used for broadcasting on the FM radio band, the sound channel for TV, and certain mobile communication systems. Phase Modulation (PM) and frequency modulation are special cases of angle-modulation signaling. Mathematically, an angle-modulated signal is represented as [13]:

$$S(t) = A_C \cdot Cos[\omega_C + \theta(t)] \quad (2)$$

where $\theta(t)$ is the instantaneous phase conveying the message signal.

For PM, the phase is directly proportional to the modulating signal as [12]:

$$\theta(t) = D_P m(t) \quad (3)$$

where $m(t)$ is the modulating signal and D_P is the phase-sensitivity of the phase modulator.

For FM, the phase is proportional to the integral according to [11]:

$$\theta(t) = D_f \int_{\to\infty}^{t} m(\sigma)d\sigma \quad (4)$$

where, D_f is the frequency deviation constant, and the instantaneous frequency of the carrier waveform conveys the message signal.

In particular, instantaneous frequency varies about the assigned carrier frequency f_C directly proportional to the modulating signal $m(t)$. The instantaneous frequency is the frequency that is present at a particular instant of time and should not be confused with the term frequency as used in the spectrum of the FM signal.

III.Challenges of Power Line Communication

Data transmission over power lines provide many attractive properties, like all other communication systems, even though, they are also at risk of attenuation, multipath, internal or external noise and disturbances [11].

Attenuation of power line is mainly influenced by cable losses and multipath. Attenuation is the loss of power of the signal during its propagation and it also depends on the physical length of the channel and transmission frequency band, and multipath caused by the impedance mismatch. Multipath can be understood as the transmitted signal reaching the receiving circuit by two or more paths with different delays [14].

The noise in the power line can be classified into 5 categories as follows [6]:

i. Coloured background noise with a relatively low Power Spectral Density (PSD), which is caused by summation of numerous noise sources of low power.
ii. Narrow band noise, mostly amplitude modulated sinusoidal signals caused by ingress of radio broadcasting stations. This type of noise consists of sinusoidal form with modulated amplitude. Several sub-bands are formed by this type of noise which are small and continuous over the frequency spectrum.
iii. Periodic impulsive noise, asynchronous to the mains frequency, which is mostly caused by switched-mode power supplies. This type of noise is in form of impulses that usually have repetition rate between 50 or 200 kHz. Switching power supplies cause this type of noise. Noise occupies frequencies that are close to each other because of high repetition rate.
iv. Periodic impulsive noise, synchronous to the mains frequency, which is mainly caused by switching actions of rectifier diodes found in many electrical appliances. This type of noise is also in a form of impulses with repetition rate of 50 or 100 Hz and is synchronous with main power line frequency. This is generally caused by power supply operating synchronously with the main frequency, such as the power converters connected to the mains supply.
v. Asynchronous impulsive noise, which is by switching transients in the power network. This type of noise impulses are mainly caused by switching transients in the network. Their power spectral density can reach values of more than 50 dB above the level of the background noise, making them the principal cause of error occurrences in the digital communication over PLC networks.

IV. Approaches for Modeling of Power Line Communication Channel

PLC channel modeling consists of investigating the characteristics of the power network as a communication channel. PLC channels suffer from a number of technical problems among which are [5]:

i. Frequency-varying and time-varying attenuations of the medium
ii. Dependence of the channel model on location, network topology and connected loads
iii. High interference due to noisy loads
iv. High non-white background noise
v. Various forms of impulsive noise
vi. Electromagnetic compatibility (EMC) issues that limit available transmitted power.

Two main approaches that can be utilized for modeling a power line communication channel are Top-down approach and Bottom-up Approach [1]:

A. Top-Down Approach

Top-down approach is the most commonly used for modeling a power line channel. This approach describes the transfer characteristics of a channel by a transfer function. The transfer function parameters are extracted from actual measurements of the given PLC channel. Using this approach in a multipath channel environment, the model characteristics can be established using experimental results. The major advantages of this approach are that little computation is needed and it is easy to implement. The major disadvantage stems from the fact that the channel model is vulnerable to errors in measurements. Mathematically, the transfer function for the channel in this approach is given as [8, 13]:

$$H(f) = \sum_{i=1}^{N} \rho_i \cdot e^{-j2\pi f t_i} \tag{5}$$

Where;

N is the number of signal flow paths

i is the each flow path

t_i is the time delay

ρ_i is the complex factor which is the product of transmission and reflection factors.

B. Bottom-Up Approach

The Bottom-up approach starts from the theoretical derivation of model parameters. This approach describes the behavior of a network by a large number of distributed components using matrices. The detailed knowledge of all components within the network is required for accurately setting up these matrices. The major advantage of this approach is that its increased flexibility and versatility due to the fact that all the parameters of the network are formulated analytically, making it easy to predict the changes in the transfer function when a different multipath network configurations are under consideration. The major disadvantages of the approach are; increased computational effort compared to Top-down approach and, there are a large number of parameters which cannot be determined with sufficient precision [7, 9].

In addition, this approach is closely related to the physics of power networks since it is derived from the physical interpretation of Electromagnetic (EM) wave propagation in transmission line networks. For a given number of paths, an estimate of the path attenuation, weighting and delay factor are determined [2].

The Multipath Model of bottom-up approach is given as [11]:

$$H(f) = \sum_{i=1}^{N} g_i \cdot e^{-\alpha \cdot d_i} \cdot e^{-j2\pi f \frac{d_i}{v_p}} \qquad (6)$$

where;

g_i = the weight of the i^{th} path determined by reflections and transmission,

d_i = the path length,

α_i = the path delay

d_i is the length of a path

v_p is the propagation speed

V. Modulation Schemes for PLC System Designs

It is necessary to select a modulation scheme that uses a high potential capacity power line channels optimally and also offers a high degree of noise robustness due to the difference in properties of power line channels compared to other well-known channels. The selection of a modulation scheme for PLC systems must account for three major factors [13]:

i. The presence of noise and impulse disturbances causing a relatively low Signal-to-Noise Ratio (SNR).
ii. The time-varying frequency-selective nature of the channel.
iii. Regulatory constraints with regard to electromagnetic compatibility that limit the transmitted power. A choice should be made of either a robust solution which provides sufficient quality for a wide range of variations of the model parameters, or an adaptive solution. The problem is further complicated in the home environment by the need to make power line-based home networking cost competitive with other wired or wireless solutions.

The following modulation schemes are basically applicable for use in power line communication.

A. Single Carrier Modulation

In a single carrier modulation, information is encoded in amplitude, phase, or frequency changes of the carrier. Dependent on this rate of change, a more or less wideband signal of bandwidth is generated around the modulated frequency. A modulation scheme can be characterized by its spectral efficiency. The spectral efficiency figure indicates the number of bits per second the scheme can encode into a 1 Hz bandwidth. Due to limited spectral resources, PLC technology must always aim at maximum spectral efficiency. However, basic single carrier modulation cannot offer more than 1 bit/sec/Hz. Moreover, implementing high data rates results in the generation of contiguous wideband transmission signals, generally centered on the carrier. Due to notches in the channel frequency response and the low-pass character of the channel, such signals are seriously affected. Hence, poor performance can be achieved [4, 7, 14].

B. Spread Spectrum Techniques

Spread spectrum techniques are good choice for PLC systems due to their immunity against frequency selective attenuation and all kinds of narrowband interference. However, the rapid development of integrated-circuit complexity has made Spread Spectrum Technique (SST) available for almost any application. An additional feature of SST, with regards to EMC, is the lower power spectral density of the transmitted signals compared to single-carrier modulation schemes. Spread spectrum techniques compared to frequency-selective channels utilizes a code sequence that spreads narrowband signals over a wider bandwidth. Its application to wireless channels takes advantage of its robustness to narrowband interference and its low power signal density spectrum. On the other hand, SST lends itself to multiple access techniques such as Code Division Multiple Access (CDMA), which allows several users, possibly with different rate demands, to access and utilize the PLC channel simultaneously [12, 13, 14].

For these reasons, much attention has been focused on multicarrier techniques, in particular Orthogonal Frequency Division Multiplexing (OFDM).

VI. Orthogonal Frequency Division Multiplexing

Orthogonal Frequency Division Multiplexing (OFDM) is a signaling technique that is widely adopted recently in standardized broadband communication systems due to its ability to cope with frequency-selective fading. OFDM is a special form of wideband multicarrier modulation in which multiple symbols are transmitted in parallel using different sub-carriers with overlapping frequency bands that are mutually orthogonal. They are used in applications such as Digital Audio Broadcasting (DAB), terrestrial Digital Video Broadcasting (DVBT) and Asymmetric Digital Subscriber Line (ADSL). An important advantage of the OFDM transmission technique compared to single carrier technique is seen in the context of frequency-selective channels [3, 9, 13].

OFDM exhibits robustness against various kinds of interference and enables multiple accesses similar to the bandwidth spreading modulation types. The spectrum used by OFDM is segmented into numerous narrow sub channels. A data stream is transmitted by Frequency-Division Multiplexing (FDM) using N orthogonal carriers, centered in the sub-channels. Due to the narrowband property of each sub-channel, attenuation and group delay are constant within each channel. Thus, equalization is easy and can be performed by using a one-tap technique. Orthogonality of all carriers leads to outstanding spectral efficiency. Two sinusoids with arbitrary phases are said to be orthogonal when the minimum frequency is attained. The sinusoidal signals used in OFDM can be defined as [6, 9, 11, 13, 14]:

$$g_k(t) = \frac{1}{\sqrt{T}} e^{\frac{j2\pi kt}{T}} \omega(t) \tag{7}$$

where ; T is the period, $k = 0,1,....k-1$ corresponds to the frequency of the sinusoidal signal, and $\omega(t) = u(t) - u(t-1)$ is a rectangular window over $[0,T]$.

The OFDM scheme uses multiple sinusoidal signals having frequency separation $\frac{1}{T}$ where each sinusoidal signal is independently modulated by the information. The information bit a_k is multiplied by the corresponding carrier $g_k(t)$ and the sum of such modulated sinusoidal signals then forms the transmitted signal. Mathematically, the transmitted signal is given as [1]:

$$S(t) = a_0 g_0(t) + a_1 g_1(t) + ... + a_{k-1} g_{k-1}(t) \tag{8}$$

$$= \sum_{0}^{k-1} a_k g_k(t) \tag{9}$$

Equation (9) indicates that each information signal a_k multiplies the sinusoidal signal having the resulting frequency k/T, and all of the modulated sinusoidal signals are added and the resulting signal $S(t)$ is transmitted over the channel.

VII. Computer Simulation of Power Line Communication

This work employed Orthogonal Frequency Division Multiplexing (OFDM) to analyze the Power Line Communication (PLC) channel. In order to perform computer simulations for the design of PLC, a comprehensive OFDM model was used for a comparative performance study using Bit Error Rate (BER) analysis of Binary Phase Shift Keying (BPSK) in conjunction with multipath channel. The simulation was carried out using MATLAB/SIMULINK with additive white Gaussian noise (AWGN) in order to obtain correct simulation performance results. This is done by determining the input signal power to the receiver, and then noise variance is adjusted for each Signal-to-Noise Ratio (SNR) value. The noise variance was then recomputed so that it is properly scaled so that the signal power is changed for the multipath channel under consideration. Two channels of PLC were considered, the worse channel was taken into account and the channel output signal power was obtained.

The transfer function for the OFDM is given as:

$$H(f) = \sum_{i=1}^{N} \frac{1}{\sqrt{T}} e^{\frac{j2\pi kt}{T}} \omega(t) \tag{10}$$

The Gaussian noise component is added to model as:

$$P_n(\eta) = e^{-A} \sum_{m=0}^{\infty} \frac{A^m}{m! 2\pi\sigma^2 m} \exp\left(-\frac{\eta^* \eta}{2\sigma_m^2} \right) \tag{11}$$

were η^* denote the complex conjugate of η.

$$\sigma_m^2 = \frac{\frac{m}{A} + Y}{1 + Y} \tag{12}$$

The parameter A is the impulsive index given by the product of the average number of impulses per unit time and the mean duration of the emitted impulses entering the receiver. The parameter Y is the ratio between the mean power of the Gaussian and the mean power of the impulsive noise component.

VIII. Results and Discussion

The result of Power Line Communication channel was presented with frequency channel responses ranging from 500 kHz up to 20 MHz. Figure 1 to Figure 4 show the frequency response and impulse response of the two channels used in the simulation model.

Figure 1 shows the relationship between the OFDM transfer function and frequency response of the PLC system for Channel P_1. The result indicated that the channel represent a good power line channel as the channel has no branches with approximately 100m length. This type of link inherits only few reflection points. Figure 2 indicates the correlation between the magnitude of the PLC channel and the impulse response of the system. The highest impulse response is at 17 seconds and the impulse was constant throughout the period. This indicated that in the residential areas with equidistant row houses connected to similar cable of lengths, the frequency response may exhibit deep notches.

Figure 3 shows the relationship between the OFDM transfer function and frequency response of the PLC system for Channel P_2. The result indicated a channel link at a length of approximately 110 m with 6 branches. This type of link may result in very steep frequency response with deep fading which increases the length of the network structure. Figure 4 indicates the correlation between the magnitude of the PLC channel and the impulse response of the system. The highest impulse response is at 17 seconds and the impulse varies throughout the period. This behavior indicates that data transmission in PLC environment needs signal to be amplified or transmitted at higher powers.

Figure 5 indicates the BER performance of BPSK modulation in the presence of AWGN channel with OFDM between the range of 0 dB to 50 dB. The result shows that non-optimal amplitude frequency response in the system does not affect the transmission of the PLC signal in the frequency bands despite the low noise signal in the system. The results show that OFDM exhibits BER performance that provides adequate transmission of information over a PLC channel.

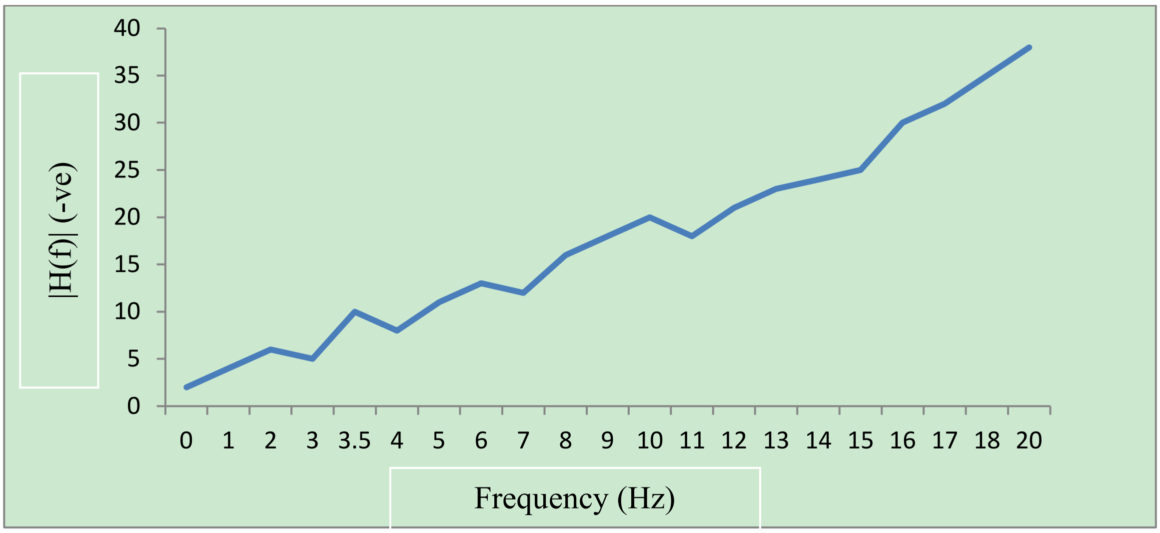

Figure 1: Frequency Response of Channel P_1

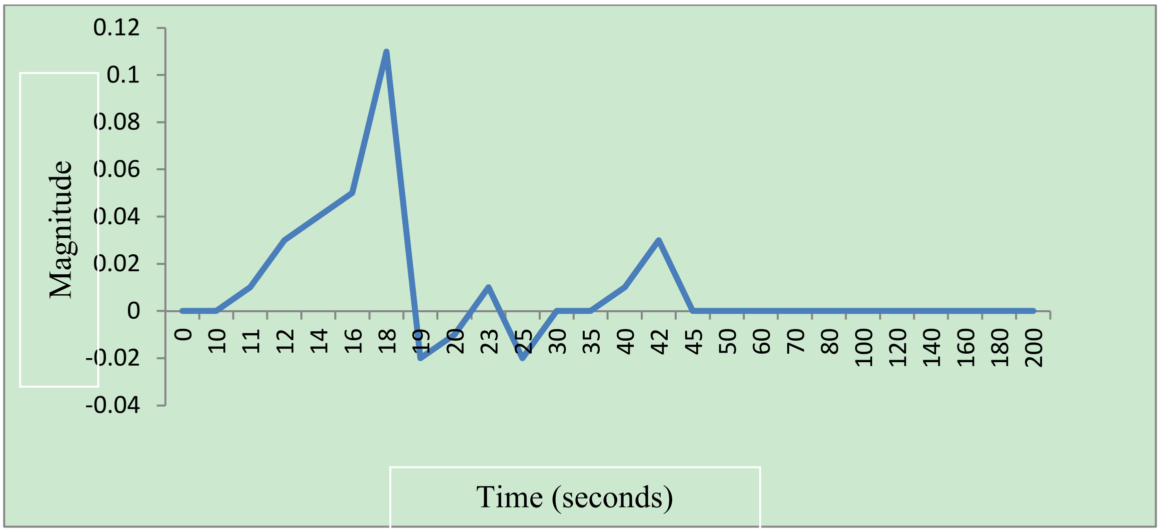

Figure 2: Impulse Response of Channel P_1

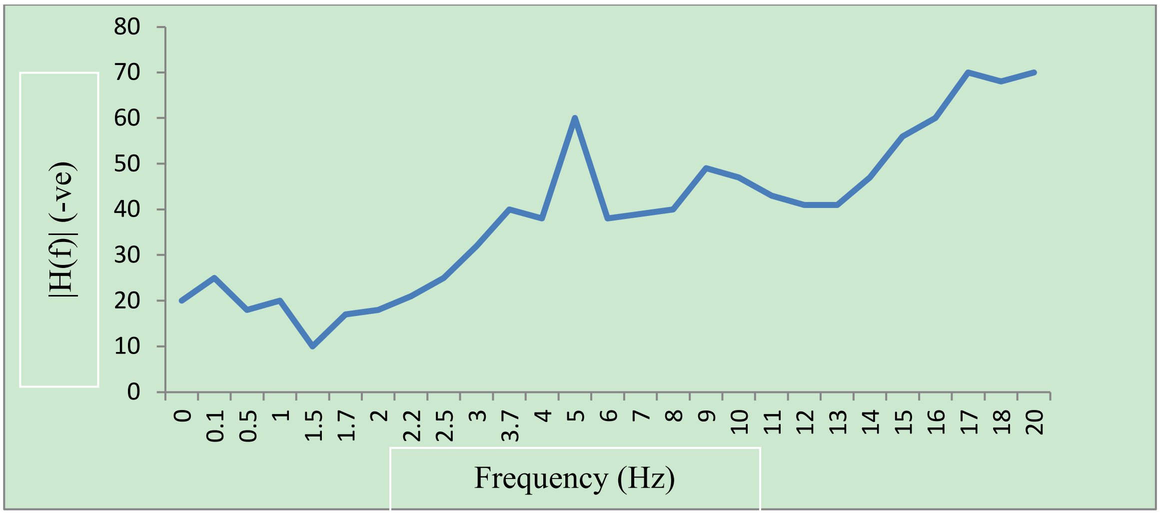

Figure 3: Frequency Response of Channel P_2

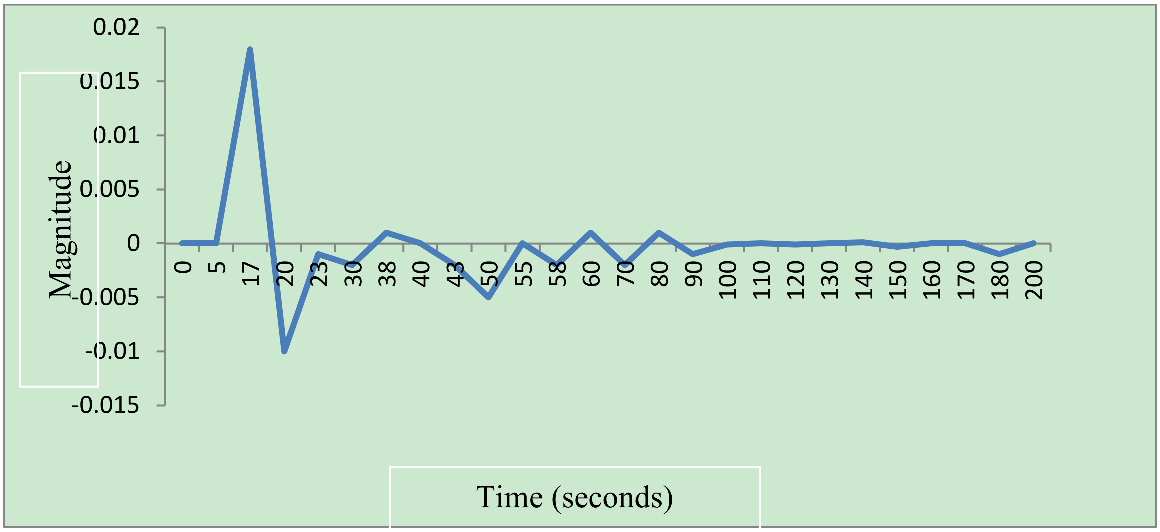

Figure 4: Impulse Response of Channel P_2

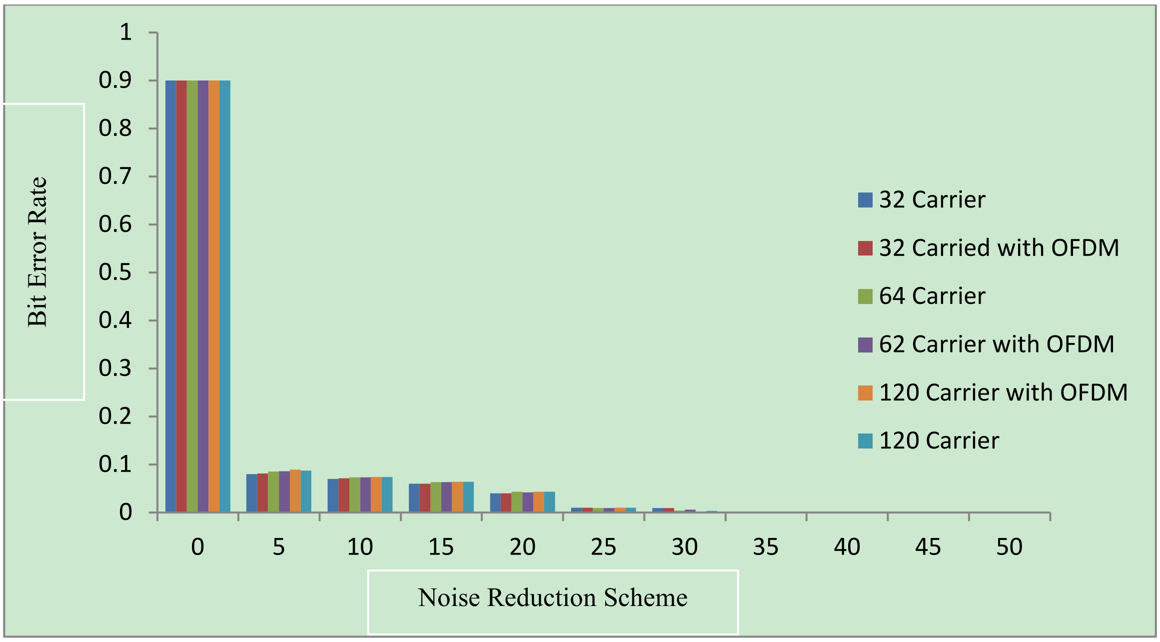

Figure 5: BER Performance of OFDM System under Multipath Effects

IX. Conclusions

This study has presented the effect of non-optimal amplitude frequency response on transmission of power line communication signals with a view to reducing the effects of noise on the system using Orthogonal Frequency Division Multiplexing (OFDM) techniques. OFDM was employed because of its robustness to noise, and the fact that it is a parallel data transmission method using a number of parallel frequency division multiplexed sub-bands. The research has presented appropriate power line reference channel models (OFDM) which form the basis for the design of a PLC system. The result of this research paper showed that non-optimal amplitude frequency response has no effect on transmission of the PLC signal in the frequency bands despite the low noise signal in the system and that OFDM exhibited BER performance that provided adequate transmission of information over a PLC channel which demonstrated the enormous potentials of the OFDM in PLC channel for high speed communication..

X. References.

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