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Development of Top-Up And Bottom –Up Techniques for Assessment of Power Line Communication Channel Model

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Abstract
Power Line Communication (PLC) is the transfer of data and voice signals from one communication system to another over the electric power delivery network. However, with the advent of technology, human dependency on electricity and communication has grown beyond leaps and bounds. The power transmission line channel has not been designed with wired channel requirements for broadband applications and appears as a harsh environment for the low-power high-frequency communication signals. This study therefore evaluate the performance of PLC on power grid by simulating a practical multipath power line communication channel model using top-down and bottom-up approach. The statistical multipath parameters such as path arrival time, magnitude and interval for each category were analyzed. This is done over the frequency range of 100-300 kHz. The result shows that at 100 kHz, data can be transmitted up to 350 meters without signal distortions while for 300 kHz only 50 meters can be covered. In addition, signal attenuation with a distance of 2 km is about 0.2 of the original signal at 300 kHz and less at higher frequencies. The results in the time and frequency domains indicate that data transmission in PLC environment needs signal to be amplified at higher powers.
Keywords: Power Line Communication, Power Grid, Transmission Line, Multipath Parameters, Channel Modelling, Top-Down Approach, Bottom-Up Approach.
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I.INTRODUCTION

Power line Communication (PLC) is an alternative method for broadband networking that has the advantage of transmitting over channels already used for electrical distribution or transmission [1]. PLC has become one important option for the required data communications infrastructure and alternative for conventional wired and wireless in-door data transmission due to the development of robust modulation, channel coding, and digital signal processing technologies. Power Line Networking enables the implementation of Local Area Networks (LANs) and fast internet amongst other applications. The broadband PLT operates in frequencies from 150 kHz to 34 MHz having a theoretical maximum speed of 200Mbps [2, 3].

The concept of communicating through PLC is quite old but not brought into use on massive scale for commercial purpose. Power companies have been using this service and keeping it restricted to them only [2]. There are several reasons that hinder PLC from being chosen as communication medium. The first and foremost reason is that power reaches the user from the point of generation via three different voltage level (HV, MV, LV). At the same voltage level, PLC allows communication while maintaining the quality well above the minimum threshold [2, 4, 5].

Another disadvantage of PLC is that a data signal injected to power line could not pass through transformer. The use of bypass devices across transformers increases the complexity and adds to overall cost [3]. Data signal is separated before the transformer instead of going through it and again injected back to the power line. Significant transmission and distribution loss of power lines is another characteristic which makes PLC a secluded option. A clique is produced when a device is switched ON or OFF in a network [2]. The Impulsive noise depletes the signal quality by introducing noise in the system. As power lines are not insulated, at high frequencies they act as an antenna hence interfering with signal being generated from high tension wire in close vicinity [4, 6, 7].

The increase in electrical supply networks informed the rapid evolution of the PLC technology and the ever increasing demands in the area of communications [5, 6]. The development of accurate PLC channel transfer characteristic models is very important as it forms the basis for computer simulations which are useful in appropriate system design and further enabling the analysis of the performance of different schemes as well as recognizing probable difficulties in the development of communication systems in different network configurations and loads [8, 9].

A PLC system is illustrated in Figure 1 where the signal tranverses from the transmitter to receiver through couplers [10]. The power line channel is mainly characterized in terms of the attenuation parameter and the impedance parameter which arises from mismatches in the power line network. The noise parameter, which is added to the signal, originates from several sources. A coupling circuit is used to connect the communication system to the power-line [11]. The purpose of the coupling circuits is inn two-folds. Firstly, it prevents the damaging 50 Hz signal, used for power distribution to enter the equipment. Secondly, it certifies that the major part of the received/transmitted signal is within the frequency band used for communication. This increases the dynamic range of the receiver and makes sure the transmitter introduces no interfering signals on the channel [2, 12, 13].

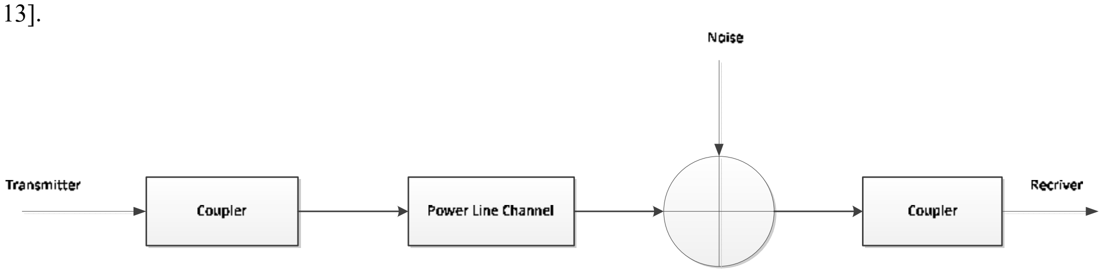

Figure 1: Simplified Power Line Communication System

A. Noise in PLC

The performance and reliability of the PLC network is affected by noise. The low-voltage (LV) power lines are a power transmission cable connecting substations to domestic houses [12]. The source of noise at Low-Voltage (LV) which is a power transmission cable connecting substations to domestic houses can be internal (inside the power network) or external (outside the power network). The noise in PLC network is classified as [13, 14]:

i. Coloured Background Noise: Is the mostly generated sources at noise of low intensity. They are characterized by a power spectral density that decreases with frequency. Appliances and components operating at low power, collectively generates noise with relatively low power spectral density (PSD).
ii. Narrow-Band Noise: Is mostly in sinusoidal form or modulated signal with various origins, and generated by the existence of broadcast waves and the instabilities caused by appliances with a transmitter or receiver.
iii. Impulsive Noise: Is considered as the most significant, and is mostly generated by electrical appliances connected to the network. It is further classified as;
   a. Periodic Impulsive Synchronous to the mains, which is generated by power supplies with silicon controlled rectifiers. Components like rectifier diodes and transistors whose cut off voltage and threshold voltages lead to switching actions.
   b. Periodic Impulsive Synchronous to the mains, which is mostly caused by switched-mode power supplies.
   c. Asynchronous Impulsive noise which is caused by switching transients in the power network.

Collective noise is the sum of all the noise types mentioned above. Colored Noise and Narrow Band Noise are considered as background noise which uniformly spread throughout the spectrum, as the rate of change of magnitude is very slow. Background noise is considered to be Additive White Gaussian Noise (AWGN) Wk for PLC assessment. The impulsive noise is given by [12, 15, 16]:

$$ik = bk*gk \tag{1}$$

where, bk is the Poisson process which is the arrival of the impulsive noise, gk is the white Gaussian process with mean zero and variance $2\sigma^2$. That is Gaussian noise of magnitude varying up to 35 dB and is distributed among data bits complying Poisson distribution. bk is the probability of getting it by noise and gk is the random variable denoting the varying amplitude of noise. The total noise nk is given by [11, 13, 17, 18]:

$$nk = Wk + ik \tag{2}$$

$$nk = Wk + bk*gk \tag{3}$$

Arrival of the impulsive noise follows the Poisson process with a rate of R units per second, so that the event of k arrivals in t seconds has the probability distribution as [17, 18]:

$$pkt = e{-}\lambda t\, {-}\lambda tk/k! \tag{4}$$

Let ak be the received signal, and then the transmitted signal rk is given by [19]:

$$rk = ak + nk \tag{5}$$

B. Multipath Channel Model of Power Line Communication

In Power line transmission the propagation of data signals do not follow single path or uni-path, but a multipath pattern similar to wireless signals that involves cellular transmission [20]. Power grid with Lower Voltage (LV) is a single central transmission line with shooting stems terminating at the end users place, as shown in Figure 2. TX is the point of transmission (substation/service provider) and RX is the point of receiver (automated meter, customer or other appliances) [12]. A small section of Figure 3 could be singled out to review multipath of propagation of signal. From Figure 3 [20];

Let D be the point of transmission and C be the point of receiving. The signal generated at point D is given as [17]:

1. D – 3 – 2 – C
2. D – 3 – 3 – D
3. D – 3 – 1 – 3 – D
4. D – 3 – 1 – 1 – 2 – C

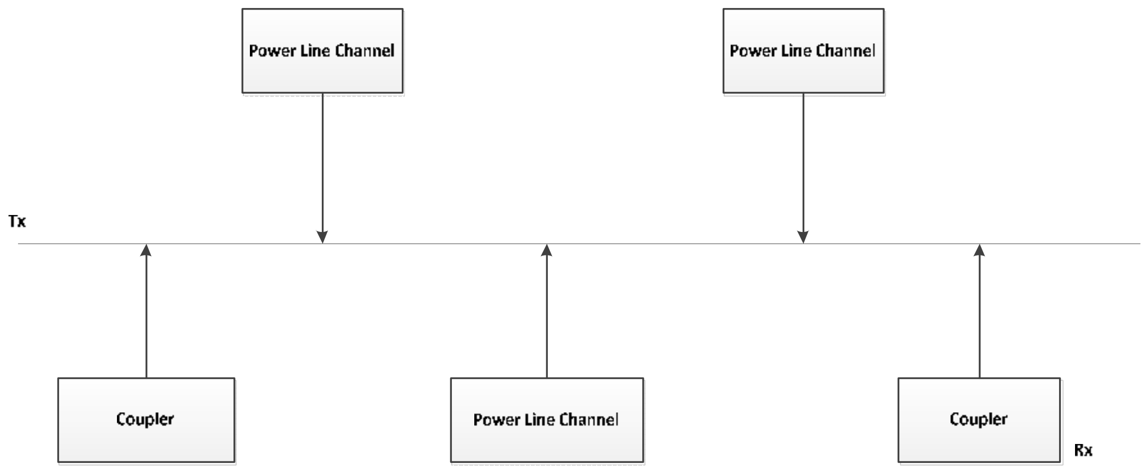

Figure 2: Typical topology of end a transmission line in power grid

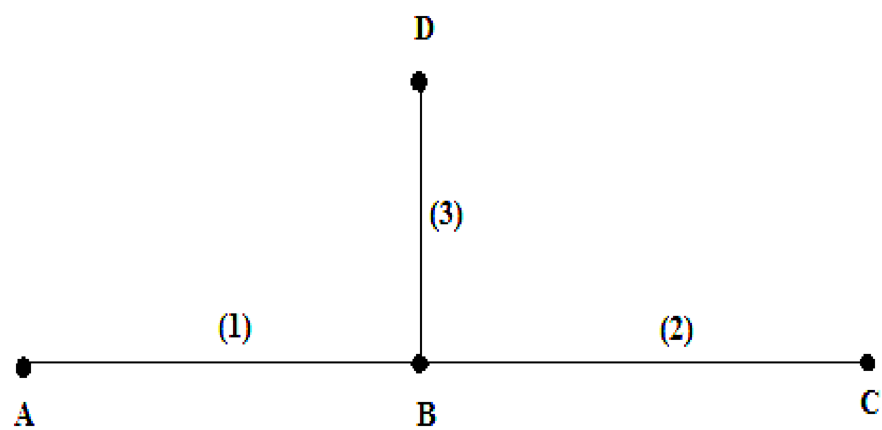

Figure 3: Multipath propagation of signal from D to C

II. MATERIALS AND METHOD.

This study used top-down and bottom-up approach to measure the channel characteristics of the power line under different network topologies and conditions.

For top-down approach, the model parameters are obtained from measurements. Little computation is necessary in this approach and it is easy to implement. The transfer function parameters are extracted from actual measurements of the given PLC channel. The transfer function for the channel is given as:

$$H(f) = \sum_{i=1}^{N} \rho_i \cdot e^{-j2\pi f t_i} \quad (6)$$

Where;

N is the number of signal flow paths
i is each flow path
t_i is the time delay
ρ_i is the complex factor which is the product of transmission and reflection factors.

The complex attenuation factor is given as:

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$$\rho_i = |\rho_i| \cdot e^{-j\varphi_i} \tag{7}$$

where;

$$\varphi_i = \tan^{-1}\left(\frac{\mathrm{Im}(\rho_i)}{\mathrm{Re}(\rho_i)}\right) \tag{8}$$

The Multipath Model channel transfer characteristic by a frequency response is given as:

$$H(f) = \sum_{i=1}^{N} g_i \cdot e^{-(a_0 + a_1 f^k)d_i} \cdot e^{-j2\pi f \tau_i} \tag{9}$$

Where;

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

d_i = the path length,

τ_i = the path delay given by the following

$$\tau_i = \frac{d_i}{v_p} = \frac{d_i\sqrt{\varepsilon_r}}{c_0} \tag{10}$$

Where;

ε_r is the insulating material's dielectric constant

c_0 is the speed of light

d_i is the length of a path

v_p is the propagation speed

For bottom-up approach power network elements are modeled mathematically and incorporated to generate the PLC channel. This approach can be applied to various situations flexibly as long as the network information is perfectly known. 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.

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

$$H(f) = \sum_{i=1}^{N} g_i \cdot e^{-\alpha \cdot d_i} \cdot e^{-j2\pi f \frac{d_i}{v_p}} \tag{11}$$

The PLC channel model is given as:

$$H(f) = \sum_{i=1}^{N} g_i \cdot e^{-(a_0 + a_1 f^k)} \cdot e^{-j2f\left(\frac{d_i}{v_p}\right)} \tag{12}$$

The transfer function is obtained by a Fourier transformation of the measured impulse response. This impulse response is represented as a sum of Dirac pulses delayed by τ_i and is expressed as:

$$h(t) = \sum_{i=1}^{N} |\rho_i| \cdot e^{-j\varphi_i} \cdot \delta(t - \tau_i) \tag{13}$$

The model is completed by assigning proper values to the above parameters. The intrinsic line parameters are derived prior to the calculation of the transfer function shown in equation (12).

III.DISCUSSION OF RESULTS

The assessment of PLC channel model is presented in Figure 4. The result was presented with frequencies channel responses of 100 kHz and 300 kHz respectively.

Figure 4 shows the relationship between the weight of the path and the path delay of PLC channel at frequencies of 100 kHz and 300 kHz. The result indicated that the highest path delay value is 0.62 seconds at 250 weight value at 100 kHz and 300 kHz. The lowest path delay values are -0.55 and -0.60 seconds at 750 weight value at 100 kHz and 300 kHz respectively. In general, the result shows that at 100 kHz, data can be transmitted up to 350 meters without signal distortions while at 300 kHz, only 50 meters can be covered. It can be observed that the signal attenuate with distances in such a way that at a distance of 2 km the signal is about

0.2 of the original signal at 300 kHz and less at higher frequencies. This behavior indicates that data transmission in PLC environment needs signal to be amplified or transmitted at higher powers.

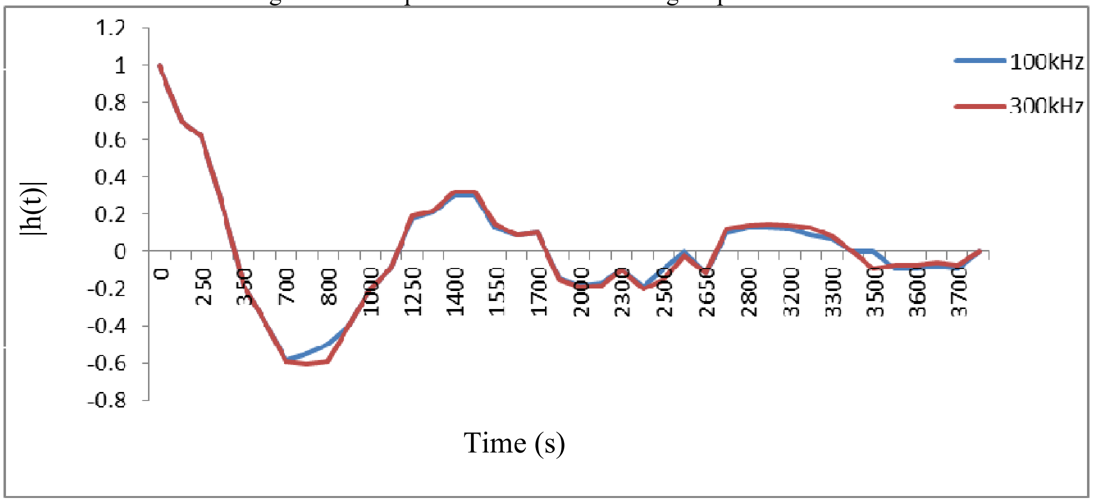

Figure 2: Time response of weight of the path and the path delay of PLC channel for 100 kHz and 300 kHz frequencies.

IV.CONCLUSION

This study has presented the assessment of power line communication channel model using both top-up and bottom-up communication techniques. In Power line transmission the propagation of data signals do not follow single path or uni-path, but they follow a multipath which is a pattern very similar to wireless signals involved in cellular transmission. This model is basically a multipath model partly cooperated with transmission line theory. The multipath nature of PLC channel is due to the presence of branches and impedance mismatches which cause multiple reflections. This study treats the PLC channel as a black box and a large number of measurements are collected by exciting the channel with a reference signal in either time domain or frequency domain.

The result shows that at 100 kHz, data can be transmitted up to 350 meters without signal distortions while at 300 kHz, only 50 meters can be covered. It can be observed that the signal attenuate with distances in such a way that at a distance of 2 km, the signal is about 0.2 of the original signal at 300 kHz and less at higher frequencies. The study revealed that there is an increase in power line communication length in deep notches which signifies attenuation on the broadband power line communication channel. The results indicated that the channel transfer function is effective for modelling the power-line communication channel.

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