Data Transfer Over Low-Voltage European Power Distribution Networks

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***Abstract:* Broadband power line (BPL) data transmission deals with transfer of data via the existing power line systems and is a fast emerging technology. The main advantage of BPL is being able to use the existing power line infrastructure, thereby reducing the cost. However, power line systems were not designed for high-speed data transmission as they consist of various branches and power line elements such as bridges, taps, transformers and capacitor banks. Therefore, the power line transmission medium not only introduces noise but is also adverse to high-speed data transfer in terms of the channel bandwidth. In this paper a power line channel has been modelled using Matlab and the effects of variations in the direct length, branch length and branch load on the channel frequency response are investigated. Simulations indicate suitability of multi-carrier transmission over the power line channels.**

***Index Terms:* Bandwidth, branch length, broadband, direct length, frequency response, load impedance, multi-path, power-line, transmission lines.**

I. INTRODUCTION

Broadband power line (BPL) communication systems are fast emerging as a cost-effective solution for broadband access networks. The main advantage of a BPL system is to use the existing infrastructure of power line networks for providing data network services to customers in areas without access to wired medium such as telephone or fibre optics cables. However power line channels present a harsh environment for high-speed data transmission [1]. The high data rate signal undergoes attenuation due to line loss and impedance mismatches of the power line elements such as branches and loads. In addition, these elements are a source of noise and interference in the transmission medium. The topology of the BPL system can vary according to distribution network in use [2]. This paper discusses the typical topology of the distribution network where the low-voltage power line system is used as the transmission medium. The topology of the low-voltage distribution network may differ from country to country and even region to the region . It varies on several factors such as user density, the distribution network length, location (commercial or residential) and the topological designs (the length of the branch, number of branches, etc.) [3]. In this paper a multi-path power-line channel has been modelled using Matlab and the effects of variations in the direct length, branch length and branch load on the channel frequency response are investigated. A power line with typical European specifications is considered [4]. Section II describes the various topologies of power line distribution networks. Section III describes the power line multi-path channel model followed by simulations which are given in section IV.

II. POWER DISTRIBUTION NETWORKS

The power distribution networks can be classified as high-voltage (HV), medium-voltage (MV) and low-voltage (LV) [5]. HV networks have voltages higher than 100kV with typical voltages of 110, 150, 220 and 380 kV. Voltage ranges for MV networks are 1kV-100kV with typical values of 10 kV and 50 kV, while the LV networks are below 1kV having voltages of 110V, 220V or 380V. As HV lines are not suitable for data transfer, conventional fibre optics or wireless radio-link is used for transmission of this data over the existing power lines with repeaters used in MV networks to mitigate the effects of noise interference. Couplers then can be used to by-pass transformers when the power is lowered from MV to LV. In [6] the effects of changes in the power distribution network topologies on the power line channel frequency response are investigated for systems used in Tanzania. This paper investigates the effects of variations in the direct length, branch length and branch load on the LV power line channel frequency response for European power distribution networks. A simple topology for such a power distribution network is shown in Fig.1. The length of the power line between the transmitter and the receiver is AC. The branch length is given by BD, where B is assumed as the midpoint of AC. The source and load impedances are given by Z_s and Z_l respectively.

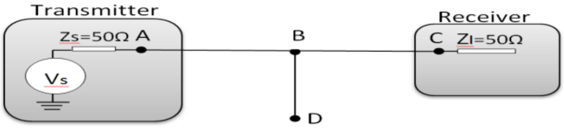

Fig.1. A simple LV Power Line network configuration

According to [4] the characteristic impedances of the power lines are connected in parallel. A typical indoor power line has characteristic impedance value which lies between 40-80Ω. Therefore, a house connection, with 10 lines connected in parallel, has approximately a 4Ω equivalent impedance. However, in practice the number of lines connected in parallel will be larger, thus causing the equivalent impedance to be close to zero at this point. In this investigation, The type of the cable used is NAYY150SE [4].

III. CHANNEL MODEL FOR BPL SYSTEM

The various power line channel models available are the Zimmermann and Dosteret model, Philipps model and the Anatory et al. model [7]. The multipath model proposed by Philpps and Zimmermann is a widely used model for investigating the data transmission over power lines and is given by [7]:

$$H(f) = \sum_{i=1}^{N} g_i \, . e^{-(a0+a1f^k)di} \, . e^{-j2\pi f d_{i/V_p}} \qquad (1)$$

where $H(f)$ is the frequency response of the channel and the various parameters used in equation (1) are given in Table I. The weighting factor g_i and the length of the data transmission path d_i for various path numbers is given in Table II where N is the total number of paths [8].

IV. SIMULATION RESULTS

This section gives the simulation results for the effects on the frequency response of the LV power line channel due to variation in length for the direct line with and without a branch; variation in length and load for the branch BD. The simulations are undertaken in Matlab.

Table I. Parameters of the model of the transfer function [8]

Parameter	Description
i	Number of the Path. The path with the Shortest delay has the index i=1
a_0,a_1	Attenuation parameters
k	Exponent of the attenuation factor (usual values between 0.2 and 1)
g_i	Weighting factor for path i, in general Complex,can be physically interpreted as the Reflection/transmission factors of that path
d_i	Length of path i
t_i	Delay of path i

Table II. Signal propagation paths of the examined network [8].

Path No	Pathway	Weighting factor g_i	Length of Path d_i
1	A→B→C	t1B	L1+L2
2	A→B→D→B→C	t1B.r3D.t3B	L1+2L3+L2
-	-	-	-
-	-	-	-
N	A→B(→D→B)$^{N-1}$ →C	t1B.r3D.(r3B.r3D)$^{N-2}$ t3B	L1+2(N - 1).L3+L2

a) *Variation in the direct line length from the transmitter to the receiver*

The topology in Fig.1 without a branch BD was employed to investigate the effects of change in the direct line length on the power line channel i.e. N=1. The length AC between the transmitter and the receiver was varied as 100m, 200m, 400m and 800m. Points A and C are matched with the characteristic impedance of the cable. The frequency response of the power line channel is shown in Fig.2. From Fig. 2 it is observed that the direct line channel topology exhibits no reflection points, i.e. there is no multi-path fading as the channel response is a linear function of the frequency. The receiver can therefore recover the data transmitted using a single-carrier modulation transmission. As the length of the direct line increases the channel bandwidth decreases indicating a direct line length of up to 100m is suitable for data transmission up to 10 MHz, even though the European specifications indicate a maximum length of 1 Km for power transmission for the length AC.

b) *Effect of varying the length AC with one branch*

The direct line length AC was varied as 100m, 200m, 400m and 800m with a single branch BD at constant length of 20m, i.e. N=2. The point D was left open leading to a reflection factor equal to 1. The multi-path behaviour of the power line channel can be observed as the notches in the frequency response and is shown in Fig.3.

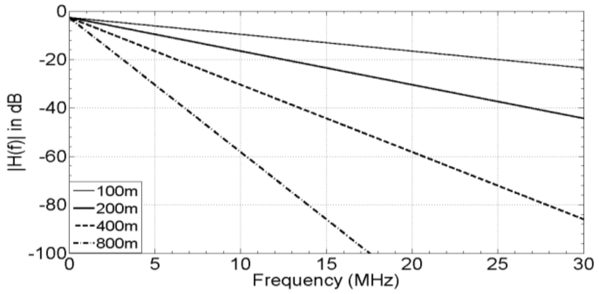

Fig.2. Frequency response for LV channel, effect of the direct length from transmitter to receiver (AC varies as 100m,200m,400m,800m) , Z_L=Z_S=50Ω.

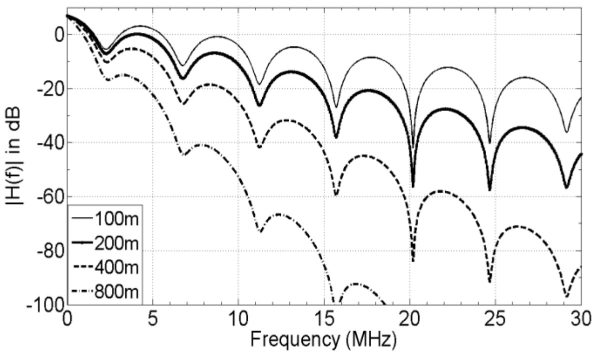

Fig.3. Frequency response for the LV channel with one branch; effect of varying the length of AC with one branch BD of 20m. AC varies as 100m, 200m, 400m, 800m.

The multi-path behaviour in Fig.3 indicates that multi-carrier transmission would be suitable for data transmission over the power line channel with this topology. As each frequency notch is spread over a spacing of 5 MHz, each sub-carrier therefore would be required to have a maximum bandwidth of 5 MHz to ensure frequency flat fading. The increase in the direct line length AC reduces the channel bandwidth and its effect on frequency response is similar to the no-branch case, the difference being that the frequency notches are superimposed on the frequency response in Fig. 2.

c) Effect of varying the branch's length

The length of the branch BD was varied from 10m to100m, while the transmitter-receiver length AC was kept constant at 100m. The branch BD was terminated at a typical value of 70Ω. The effects of change in BD with AC kept constant at 100m are shown in Fig.4. From Fig.4 it is observed that increasing the branch length BD increases the power line attenuation which is especially noticeable in higher frequencies.

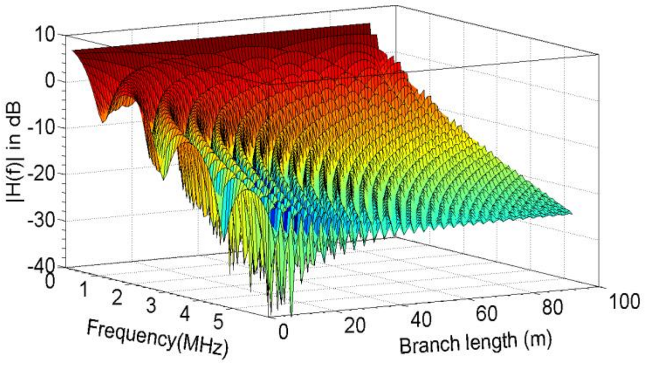

Fig. 4. Variation in the frequency response for the LV voltage channel with change in branch of length.

d) Effect of varying the branch's load

The frequency response for the branch load values of 40 Ω and 80 Ω is shown in Fig.5. The direct line length AC and the branch length BD were kept constant at 100m and 20m respectively. The branch load considered is at the termination point D of the branch. It observed from Fig.5 there is marginal change in the frequency response as the branch load is changed from 40 Ω to 80 Ω.

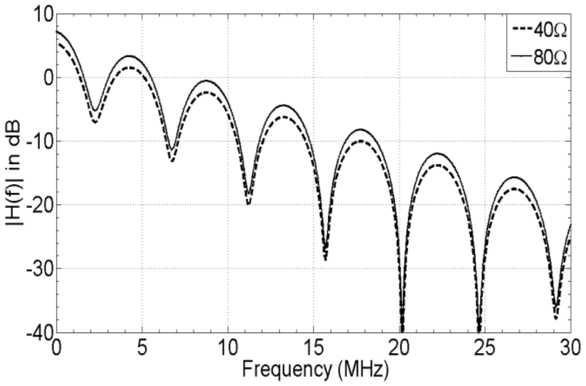

Fig.5. Variation in the LV channel frequency response with change in branch from 40Ω to 80Ω.

V. CONCLUSIONS

Various studies undertaken in Africa have indicated that BPL systems can use the existing LV power distribution networks as the 'last mile' alternative for network data transfer. In this paper the channel frequency response for the European LV power distribution networks is investigated. The frequency response indicates a multi-path transmission which is as expected due to various branches present in the transmission path. Multi-carrier transmission therefore is a suitable transmission scheme for data transfer over such networks. The effects on the frequency response for more complex topologies for European power distribution networks, including noise interference is currently being investigated and would be published in a future publication.

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