INVESTIGATION OF INDOOR LOW-VOLTAGE CABLES AS DATA COMMUNICATION CHANNELS

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ABSTRACT

Power Line Communication (PLC) has been considered as attractive media for high speed data transmission, particularly for applications like home networking, internet, voice and data services. For the use of the low voltage networks as high speed data channel the path carrier frequencies within the range up to 30 MHz must be considered. The development of suitable communication systems and the planning of PLC networks require modelling of the transfer characteristics of the main network in the mentioned frequency range. In this paper the considered PLC channel is the North Delta Electricity Distribution Company (NDEDC) indoor low voltage cables (16 mm^2 *CU/PVC). The frequency and phase responses of a single-phase power line channel with interconnections are derived. The channel transfer function is obtained and investigated using different cable lengths, and different number of branches under a given loading conditions. Loading mismatch at different branches is considered. Transfer characteristics of power line channel from Energy Meter (EM) to End User (EU) have been modelled using chain matrix method. Simulation results indicate that there are significant attenuations and distortions as the number of branches, cable length, and load mismatch are increased. The model is simulated using MATLAB environment as an effort to investigate the effects of cable length, load mismatch, multi-branches on the transmitted data signal through the considered PLC channel.*

INTRODUCTION

Signal transmission over power lines or Power Line Communication (PLC) is nowadays gaining more and more interest for applications like Internet, data services, and voice transmission. PLC offers a convenient and inexpensive medium for data transmission, however this technology still face difficult challenges.

The modeling of the PLC channel is of fundamental importance, since the quality of the transmission is highly influenced by the characteristics of the channel itself. Among the challenges of PLC technology, it is important to mention the difficulty in predicting the signal attenuation. The main reason is given by the fact that the channel is time and frequency variant, and is characterized also by being location dependent, according to the network topology, which is often unknown. In principle, Channel attenuation depends on the characteristics of the cables (length, per-unit-length parameters, frequency dependence) and of the loads [1]. Power line networks are found to be a promising infrastructure for broadband communication services. The network could be classified as indoor voltage channel, low voltage channel and medium voltage channel based on the transmission voltage levels [2]. For the design of appropriate PLC networks with considering the hostile properties of power line channels, models of the transfer characteristics of the low voltage mains network are required. Generally the PLC channel can be modeled using the chain matrix theory, based on this theory the transfer function of a "sampled or branched" power line channel can be obtained. The considered PLC channel in this paper is the indoor low voltage power line cables which are used in the Egyptian North Delta Electricity Distribution Company (NDEDC).

The simulation results can be obtained by applying the methodology of PLC chain matrix model with different cable lengths, different number of bridge taps with different equivalent impedances, and different loading conditions.

POWER LINE CHANNEL MODELING

The channel transfer function is calculated according to [3], where the two-conductor transmission-line modeling via chain matrices is used to model the indoor power-line channel. This channel modeling approach is practical and provides improved accuracy, since it takes into account the topology of the link, the particular wiring practices, as well as the cable characteristics. The electrical components between two nodes X and Y of the power-line network are described by the transmission matrix [4] [5].

$$T_{XY} = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \quad (1)$$

It is considered that a source with voltage V_S and impedance Z_S is connected to a load with voltage V_L and impedance Z_L via a two-port network. A communication channel can be represented as a two port channel as shown in fig. 1, and can be described using an ABCD matrix. The transfer function is expressed as the ratio of the voltage on the load to the source voltage

$$H(f)= \frac{V_L}{V_S} = \frac{Z_L}{CZ_L Z_S + DZ_S + AZ_L + B} \quad (2)$$

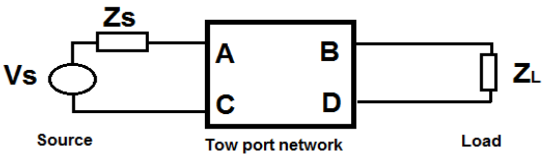

Fig. 1. Two port PLC channel with chain matrix

In the case of a uniform two-conductor transmission line, the ABCD coefficients of the corresponding transmission matrix are given as follows

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix} = \begin{pmatrix} \cosh(\gamma l) & Z_C \sinh(\gamma l) \\ 1/Z_C \sinh(\gamma l) & \cosh(\gamma l) \end{pmatrix} \qquad (3)$$

Where: γ, l and Z_C are the propagation constant, the length, and the characteristic impedance of the power line cable. In order to compute the ABCD coefficients of the transmission matrices, the propagation constant and the characteristic impedance of the power-line cable have to be computed. γ and Z_C are frequency dependent parameters and are calculated according to the following equations:

$$\gamma = \sqrt{(R+jwL)(G+jwC)} \qquad (4)$$

$$Z_C = \sqrt{\frac{R+jwL}{G+jwC}} \qquad (5)$$

Where: R, G, L, and C are the resistance, conductance, inductance, and capacitance of the power line cable, respectively. In this study the values of R and G are considered as frequency dependent parameters taking into account the skin effect of cable resistance and not like [4], where these parameters have been taken as fixed values. The cable parameters can be calculated using the literature equations [6], the technical data presented in the catalogue of NDEDC indoor cables can be used as a guide in calculations. In this study, a 16 mm^2 copper wire with PVC insulation is considered for the computation of the aforementioned cable parameters.

The chain rule [3] [4] allows for the easy calculation of the transfer function for power-line links that consist of several sections with different types of cables and various lengths. In such cases, the overall transmission matrix of the end-to-end link can be computed as the product of the individual transmission matrices of the single network sections.

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix} = \prod_{i=1}^{n} \phi_i \qquad (6)$$

Where: the ABCD is the overall transmission matrix, i is the section number, n is the total number of sections and ϕ_i represents the transmission matrix of each single network section. According to these computed parameters the transfer function of the PLC channel is obtained.

The MATLAB environment has been used to generate the required scripts to code the channel parameters and equations.

PLC MODEL WITH LOAD MISMATCH

This model is applied to the indoor cables that are used from Energy Meter (EM) at house bracket up to End User (EU). Uniform cable has been used in this PLC channel model. The cable lengths are kept constant while the effect of varying source impedance at the start of the transmission line model, which is improperly matched with that of the load impedance, is investigated. Fig. 2 illustrates the magnitude of the transfer function of PLC chain matrix model vs. frequency for the case of constant load impedance ZL of 60Ω and varying source impedance Zs of 0, 50, and 100Ω for a 2m cable length.

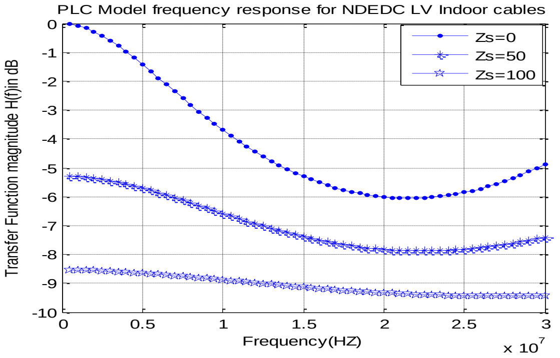

Fig. 2. Transfer function magnitude vs. frequency for indoor PLC model in case of varying Zs.

It can be seen from fig.2 that as the source impedance, Zs increases, the attenuation increases also providing that the load impedance ZL is kept constant.

Fig.3 illustrates the magnitude of the transfer function of PLC model vs. frequency in the case of constant input impedance Zs of 60Ω and varying load impedance ZL of 50, 60, and 100Ω for a 2m cable length.

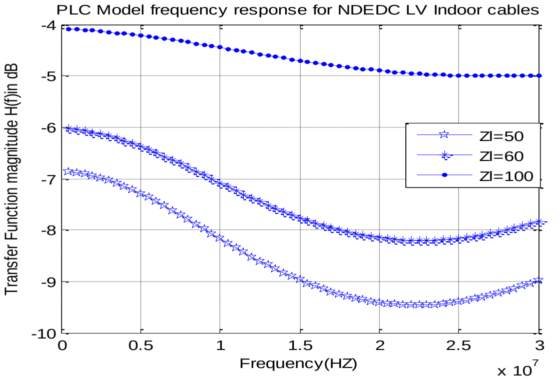

Fig. 3. Transfer function magnitude vs. frequency for indoor PLC model in case of varying Zl.

From fig.3, it can be deduced that as the load impedance Zl increases, the attenuation gradually decreases providing that the input impedance, Zs is kept constant.

PLC MODEL WITH CABLE LENGTH

Transfer function for two different power line configurations is tested in this study. The first configuration, discussed in this section, is that of a uniform transmission line model. The second configuration, in next section, takes the partitioned power line into consideration. In this section, the effects of cable lengths on the attenuation of the transmission line are investigated under similar loading conditions. Fig. 4 determines the transfer function magnitude against PLC frequency in the case of fixed loading conditions (Zs = 50Ω and Zl = 60Ω) and a varied cable length of 0.5,1,2 m.

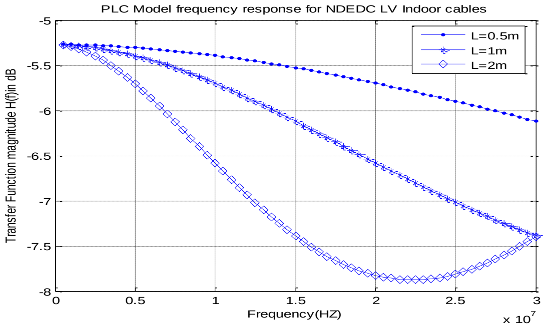

Fig. 4. Transfer function magnitude vs. frequency for PLC model in case of varying cable length L.

From fig. 4 it can be deduced that as the cable length increases the attenuation gradually increases. This can be justified with the fact that with longer cable lengths, the signal will be exposed to interference; hence, the signal strength will gradually decrease over the distance.

PLC MODEL WITH PARTITIONED CABLE

This section investigates the effect of partitioned power cable with one Bridge Tap (BT) on the PLC signal in indoor LV PLC channel model, phase and frequency response, under mismatch and match load conditions. This bridge tap has same lengths and different load impedances. Fig. 5 describes the transfer function phase and magnitude vs. frequency for PLC indoor model, in the case of load mismatch conditions (Zl=60 Ω, Zs=50 Ω), cable length of 20m, bridge tap length of 5m, and bridge tape load impedance of 50 +j100Ω.

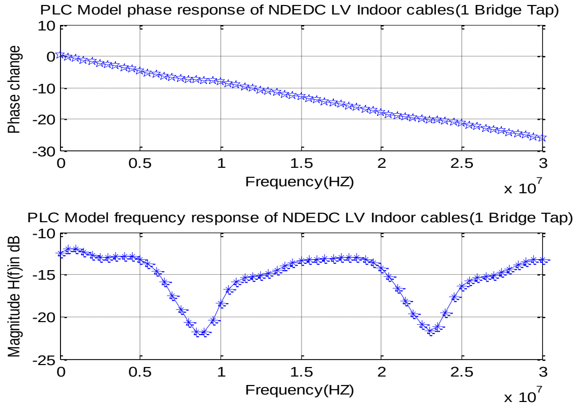

Fig. 5. Transfer function magnitude and phase response vs. frequency for PLC model, case of 1 BT with load mismatch.

Fig. 6 shows the same channel conditions of fig. 5 with matched load conditions of (Zl=Zs=50Ω) and neglecting the imaginary part of bridge tap load impedance (Zbt=50Ω). It can be seen from fig. 5 that the transfer function of PLC model has notches due to the alternating of attenuation levels between high and low values with a corresponding nonlinear parts on the phase response of the transfer function curve, while in fig. 6 the transfer function curve is continued without notches and has lower attenuation values.

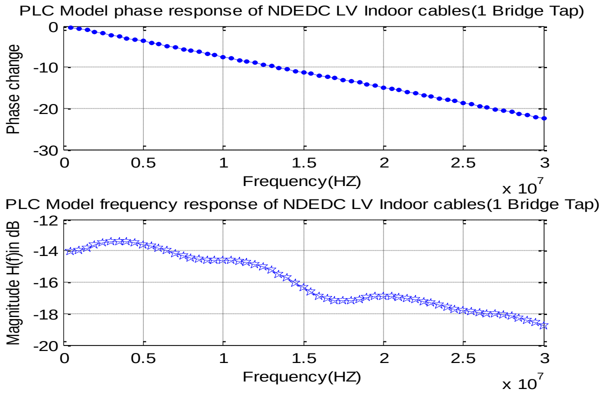

Fig. 6. Transfer function magnitude and phase response vs. frequency for PLC model in case of one BT with load match.

From figs. 5 and 6 it can be concluded that, for a partitioned PLC channel with one BT, load mismatch causes increased attenuation level and phase distortion corresponding to the notches on the transfer function curve.

PLC MODEL WITH MULTIPLE BTs

This section discusses the partitioned indoor power line cable with multiple bridge taps. The partitioned cable includes a PLC channel with five BTs. Fig. 7 shows the transfer function magnitude and phase response vs. frequency for indoor PLC channel model with five bridge taps, in the case of load conditions of ZL=60 Ω, Zs=50 Ω, cable length of 10m, the five bridge taps of lengths 2, 5, 1, 2, and 1 m respectively, and each bridge tap has load impedance of 50+j100Ω, 150 Ω, 450 Ω, 100+j50 Ω, and 200 Ω respectively.

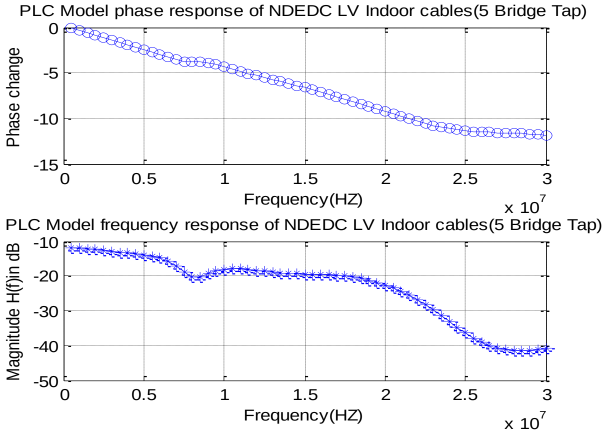

Fig. 7. Transfer function magnitude and phase response vs. frequency for PLC model in case of 5 BTs with load mismatch.

From fig. 7 it can be deduced that as the number of bridge taps increases, the attenuation significantly and rapidly increases. Multiple BTs with varying length means multiple interferences. In addition the phase response of the transfer function is influenced at the part of the indoor PLC channel that has high values of attenuation.

PLC WITH CABLE LENGTH & MULTIPLE BTs

This section investigates the effects of power line channel length with five BTs at different values of frequencies on the magnitude of transfer function and phase changes of PLC channel. Fig. 8 shows the transfer function magnitude and phase response vs. PLC cannel length for indoor PLC model, in the case of fixed load conditions of ZL=60 Ω, Zs=50 Ω, varied cable length of 0:100 m, at different frequency values of 20 MHZ, 25 MHZ and 30 MHZ, with five BTs of lengths 2, 5, 1, 2, and 1 m respectively, and each BT has load impedance of 50+j100Ω, 150 Ω, 450 Ω, 100+j50 Ω, and 200 Ω respectively.

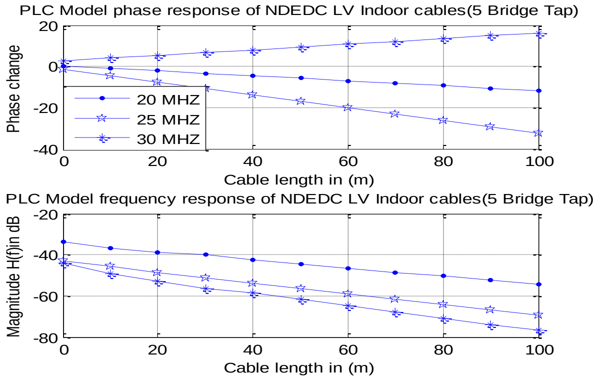

Fig. 8. Transfer function magnitude and phase response vs. cable length for PLC model in case of 5 BTs with load mismatch.

It can be seen from fig. 8 that, for the listed loading and bridge tap conditions, the maximum values of attenuation are at frequency of 30 MHZ and cable length of 100 m, while minimum values of attenuation are at 20 MHZ. It can be deduced that the appropriate signal frequency for this type of PLC channel is 20 MHZ.

CONCLUSION

Due to the structure of electric power distribution networks, high-frequency signal propagation is mainly influenced by two effects: attenuation caused by cable losses, increasing with frequency and length, and multipath propagation arising from branching and unmatched line ends. This paper introduces a discussion of these effects on the PLC channel. The considered channel of this study is the indoor low voltage power line cables which are used in the Egyptian NDEDC. Based on the chain matrix theory, the transfer functions of a sampled and branched power line channel have been obtained. The transfer function model of the channel is simulated using MATLAB, and the effect of using different loading conditions, cable lengths and number of bridge taps on the efficiency of the communication channel is investigated.

Simulation results indicate that there are significant attenuations and distortions as the number of branches, cable length, and load mismatch are increased.

This results act as a guide in the applying of the PLC technology in a developing country like Egypt.

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