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MODELING OF LINE PARAMETERS FOR THE BROADBAND POWER LINE CARRIER CHANNEL

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Abstract- High speed data over power line seems as unique solution for the sparsely populated areas. Several research and field experiments have been done to investigate the feasibility of this communication channel. The aim of this article is to simulate the high speed data communication via power cables. The effect of physical properties of power line on data communication is investigated. The research steps are mathematical and physical analysis and programming. The effects of line material, line diameter, line elevation, line span and termination on spectral response of channel for various frequencies are investigated. It is seen that copper as line material, thick wires, short towers, line with the least span and resistive-inductive loads shows the maximum voltage amplitude at the load.

Keywords: Data Communication, Power Line Carrier, Broad Band Power Line Communication.

I. INTRODUCTION

During the last decades, trends to broad band communication systems enforce the networks operators to install new communication channels from data providers to the consumers at the last mile. The key technical issue that prevents the operator is the cost of channel installation, especially for the sparsely populated areas. Fiber optic is the ideal communication channel for the broadband data communication. Its high capacity, immunity against the electromagnetic interference, made it the first choice for the network planner. However due to installation cost, it is expensive for the sparsely populated areas.

Wireless communication systems; do not require any material as its transmission channel. Only with installation of transmitter and receivers, a broadband data communication network can be constructed. Wireless local loops (WLL), Local Multipoint Distribution Systems(LMDS) and Multipoint-Multipoint Distribution Systems (MMDS) are some examples of wireless systems that can be installed for broad band data communication. There are many data security and wave propagation issues that limits the usage of these technologies.

Recently data provisions from digital broadcast networks are considered. These networks require suitable return channel that prevents their growth. In the recent years broad band data communication via power cable is considered for the providing data to sparsely populated areas. The history of this type of data communication comes back to 1920s, when low rate operation and control data for power network operators have been put into the power cable. With the advances in communication theory (modern modulation and coding schemes) and microelectronic industries (i.e. integrated circuit technologies that provide high computation speed), researchers have focused on the high bit rate data over power line. A broadband power line communication system is considered for communication of operation and control data in small grids. Several standards are provided in this regard. BPLC can be used for traffic light control and automatic metering systems [1-11].

Data rendering by power transmission cables PLC is suitable solution for reducing of providing price for high speed data communication. The power transmission cable penetration rate is more than communicational cables and wiring for services initiation is unnecessary. Generally PLCs are divided to two, narrow band and widths band. Already power transmission cable has been used as transmission environment for transmitting of data with low rate. The used frequency band in this system is bound to 125 KHz and the simple modulations schemes like the ASK, PSK, FSK are used for transmitting of data in this systems. The Broad Band Power Line Communication systems provide more data rate than past PLC system. This fact is achievable by using of larger frequency band and more complex modulations.

In order to achieve the Broad Band Power Line Communication signals through distribution transformers, there is need for equipments to bypath high frequency signals. Linear (due to eddy current and hysteresis) and nonlinear characteristics of distribution transformers prevents the high frequency signals. One of major problems using of this technology is that used external electrical lines are not protected and unprotected high frequency may interfere other wireless signal in.

By using the electrical tools for providing access internet and high speed lines, the high frequency data are supermised on the transmission line's voltage. In this method, modems beside the distribution posts couple the data to the line. This technology has been accomplished successfully in Europe, where the main voltage of transformers for residential regions is almost 220. Totally, data transmission methods in industrial communication systems could be studied in general 3 states (i.e. carrier band, broad band, base band). In base band, data transmission is done by series of signals without change to frequency but in broad band, data deliver at broad frequencies ranges in one channel. In carrier band, only one frequency is used for transmitting and receiving data [12-17].

The Broad Band Power Line Communication system in addition to modem consists of 3 major parts as shown in Figure 1:

1- Transformer's intersectional equipment (coupler).
2- Input gate to operating equipment and shares.
3- head-end router serve device.

The data transmission process includes data flow through head router server to modem and modulated their and transmitted to moderate voltage coupler. Any distribution transformer has one coupler that separated modulated signal and transmitted to pole-top case. This case demodulates and produces data bites and transmits to installed modems in system by weak pressure system. Thus data transmits from one server to user.

One of system problem is possibly of overlapping with noises driven by using equipments in appliance and industries. In order to prevent the PLCs destructive effects, efficient modulations should be used. Also using suitable coding mitigates the distortion effect. Unfortunately, there is not special standard for physical layer and MAC layer of PLC systems and each PLC systems operator has been a selected differential solution that is not consistent with other. However a lot of countries have been tried to use BPLC for commercial applications. For example in Japan, until the end of 2004, the effectiveness of this system was surveyed and then the possibility of it for commercial application has been studied. In some countries such as American and Germany, this system has been used commercially and in some others such as England, French, China and Korea, it is under evaluation.

Several field experiments are reported. A brief review for BPLC in Japan can be found in [1]. G. Lee et. al. demonstrate the technology status in United states [2]. Zimmermann et. al. discuss low voltage distribution network as last mile access network in the HF- range. A comprehensive review about the theoretical and technological aspects of BPLC can be found in [4].

Noise and EMI due to BPLC is the main problem for development of the BPLC [5-9]. A standard for the EMI can be found in [7]. A test-bed for power line communications can be found in [10]. A model for the channel can be found in [11]. This is a rapidly developing research area and its various features are under investigation by several authors [18-20]

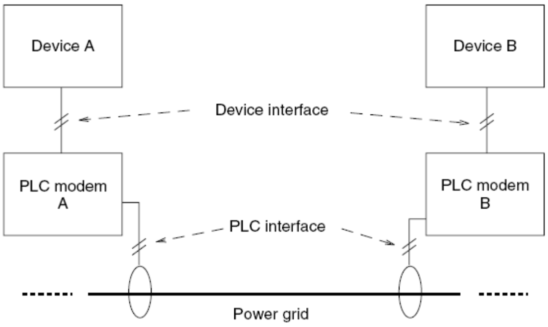


Figure 1. Structure of communication over power line

The aim of this article is to simulate the high speed data communication via power cables. The effect of physical properties of power line on data communication is investigated. The research steps are mathematical and physical analysis and programming. In the other word, the research steps are: to extract the distributed equation of power line for the transmission lines with the known parameters, solution of equations with the transfer function method, implementing the algorithm with MATLAB and investigation effects of the line parameters (such as line shape, line material, height, and termination effect) on the channel characteristics by the implemented software.

II. POWER LINE MODELING AT BPLC FREQUENCIES

A. Transfer Functions for Uniform Transmission Line

At the BPLC frequency band, only distributed models can be utilized for the modeling of voltage and currents along the line. In this approach, transmission line can be modeled by the distributed series inductors and shunt capacitors (Figure 1). For the two wire line:

$$l = \frac{\mu_0}{\pi} \ln \frac{D^2}{a^2}$$
$$c = \frac{2\pi\varepsilon_0}{\ln \frac{D^2}{a^2}} \tag{1}$$

where D and a are lines spacing and diameters, respectively. The governing equations for the voltage and current waves are

$$\frac{\partial v(z,t)}{\partial t} + \frac{1}{c}\frac{\partial i(z,t)}{\partial z} = 0$$
$$\frac{\partial i(z,t)}{\partial t} + \frac{1}{l}\frac{\partial v(z,t)}{\partial z} = 0$$

with the end points boundary conditions as

$$v_g = v(0,f) + Z_s i(0,f)$$
$$v(L,f) = Z_L i(L,f)$$

These equations can be solve either in time domain with appropriate discrediting the equations, or in frequency domain by Fourier transform with respect to time. In this paper we solve equations in the frequency domain. Transfer parameters for the line can be found as:

$$A = D = \cos\beta l$$
$$B = jZ\sin\beta l$$
$$C = \frac{j\sin\beta l}{Z} \tag{2}$$
$$T = \begin{bmatrix} A & B \\ C & D \end{bmatrix}$$

where $\beta = 2\pi f\sqrt{LC}$ and $Z = \sqrt{\frac{L}{C}}$.

Finally the transfer function (i.e. the ratio of output voltage to input voltage) can be determined as:

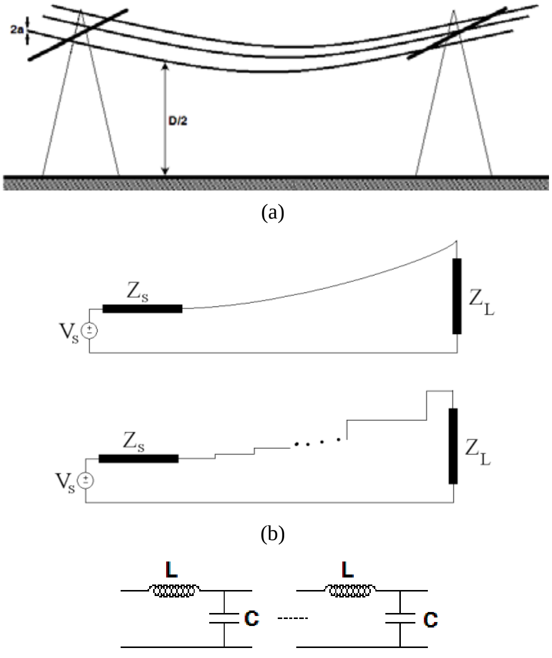
$$H(f) = \frac{V_o}{V_S} = \frac{1}{A + \frac{B}{Z_L} + CZ_S + D\frac{Z_S}{Z_L}} \tag{3}$$

where Z_L and Z_S are the source and load impedances, respectively.

B. Transfer Function for Nonuniform Transmission Line

Earth gravity, causes span along the line and affects the electrical parameters of the channel. In order to model this effect, we approximate the non-uniform line with staircase uniform lines with varying elevation, as shown in Figure 2. The transmission matrix of staircase combination of uniform transmission line can be found by multiplication of transmission matrices of each of lines. After calculating the transmission matrix, the transfer function can be found using the Equation (3).

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \left(\prod_{j=1}^{N-1} \begin{bmatrix} A_j & B_j \\ C_j & D_j \end{bmatrix} \right) \begin{bmatrix} V_N \\ I_N \end{bmatrix} \tag{10}$$



(a)

(b)

(c)

Figure 2. (a) Geometry of nonuniform power line, (b) its transmission line equivalent and (c) distributed equivalent circuit for the transmission line at the BPLC frequencies

III. SIMULATION RESULTS

A program in MATLAB was written for the simulation of channel characteristics. The effects of line material, line diameter, line elevation, line span and termination on spectral response of channel for various frequencies was investigated.

A. Line Material

Table 1 shows the effect of line material on the frequency response. Three materials, including copper, anodized copper and aluminum is considered as the core material. It is seen that in all frequencies, copper reveal the least loss. As the Table 1 shows, by increasing the frequency, the loss increased, regardless of the core material used.

Table 1. The effect of line material on channel attenuation

	Copper	Anodized Copper	Aluminum
5 MHz	0.736	0.7335	0.6904
10 MHz	0.6635	0.6603	0.6063
15 MHz	0.6023	0.5989	0.5412
20 MHz	0.5734	0.5695	0.5049
25 MHz	0.5406	0.5365	0.469
30 MHz	0.5064	0.5023	0.4349

B. Line Diameter

Table 2 shows the effect of the wire diameter on the frequency response. It is seen that by increasing the wire diameter, the attenuation is monotonically decreases, in all frequencies.

Table 2. The effect of line diameter on channel attenuation

a (mm) *f* (MHz)	5	10	15	20	25	30
5	0.086	0.303	0.016	0.00862	0.005	0.003
10	0.257	0.153	0.103	0.074	0.0553	0.0424
20	0.472	0.354	0.287	0.238	0.204	0.176
30	0.595	0.477	0.417	0.362	0.327	0.293

C. Line Elevation

The effect of line elevation on channel response can be found in Table 3. There are not regular variations. It seems that in high frequencies, increasing the tower height, the loss is increased.

Table 3. The effect of line elevation on channel attenuation

f *h*	12 m	18 m	24 m	36 m
1.2 MHz	1.0235	0.989	0.9656	0.9327
5 MHz	0.7836	0.7872	0.7893	0.7918
15 MHz	0.6988	0.7054	0.7093	0.714
30 MHz	0.622	0.631	0.637	0.644

D. Line Span

Table 4 shows the effect of line span on the frequency response. It is seen that by increasing the line span, the output amplitude is decreased. It is due to increasing the line length, and consequently the line overall loss.

Table 4. The effect of line span on channel attenuation

f (MHz) Span (m)	50	80	100
5	1.057	1.0305	0.8674
15	0.8656	0.8346	0.805
30	0.9331	0.7945	0.7501

E. Termination load

Table 5 shows the effect of termination load on the frequency response. In this regard restive, resistive-capacitive, resistive-inductive and resistive-inductive-capacitive loads are considered as the line termination. It is seen that in all frequencies, resistive inductive load reveals the largest voltage amplitude.

Table 5. The effect of Termination on channel attenuation

Load / *f* (MHz)	Resistive	Resistive-Inductive	Resistive-Capacitive	Resistive-Capacitive-Inductive
0.1	0.8185	0.8175	0.8188	0.8179
5	0.8033	0.9843	0.8369	0.876
15	0.6991	1.2972	0.898	1.0517
25	0.6365	1.3131	0.9818	1.1438
30	0.5713	0.8115	0.7446	0.7836

IV. CONCLUSIONS

The effects of line material, line diameter, line elevation, line span and termination on spectral response of channel for various frequencies are investigated. It was shown that using copper as line material, thick wires, short towers, line with the least span and resistive-inductive loads shows the maximum voltage amplitude at the load.

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BIOGRAPHIES

Mehdi Rashidi was born in Tabriz, Iran, 1978. He received the B.Sc. degree from Islamic Azad University, Tabriz Branch, Tabriz, Iran and the M.Sc. degree from Iran University of Science and Technology, Tehran, Iran. Since then he taught the courses in several universities. He has published several papers in national and international conferences. His main research interest is application of information technology in power engineering.

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