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Power Line Modeling and Effect of Line Length for Substation Monitoring Using Broadband

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Abstract:
The objective of this paper is to study the feasibility of Broadband technologies for substation monitoring in an effective manner and to develop a simplified transfer characteristic model for the low voltage indoor power line for Broadband power line communication based on the transmission line theory using software simulation for generalization purpose as it is already known that there is no such thing as a standard "power line network". A bottom-up approach based on the frequency-domain modeling and using scattering matrix is implemented for channel modeling in this paper.

Keywords: *Broadband, Substation automation, Power line communications, Channel model, Transfer function*

1. Introduction

THE operational and commercial demands of electrical utilities require a high performance data communication network that supports both existing functionalities and future operational requirements [8]. A solution to this is the use of Broadband technologies. Broadband technologies can offer an alternative communication network to remotely control and monitor substations in a cost-effective manner with its already existing communication infrastructure. As already mentioned in [9] the application of Intranet technology will allow information related to the condition and performance of the primary plant, such as circuit breakers and transformers to be released from the closed substation information system. The key component is the substation information management unit, which will act as a data base converter. It will compress data with closed format from substation equipment, convert data to information and provide this information via the wide area network.

An alternative to broadband technologies is broadband power line communications. Broadband PLC when overlaid on the electric grid provides users with communication means over existing "power lines". The new technology operates in the 1-30 MHz and can deliver data rates up to several Mbps [1]. The rationale behind providing high bit-rate data services exploiting the power grid resides in the vast infrastructure in place for power distribution, and the penetration of the service could be much higher than any other wire line alternative. In spite of the renewed interest in Power line communications, this technology still faces several technical challenges and regulatory issues: the power line channel is extremely difficult to model; it is a very noisy transmission medium; Power line cables in the 240V secondary distribution systems are often unshielded, thus becoming both sources and targets of electromagnetic interference (EMI); transformers can introduce severe distortion in the absence of bypass couplers. Due to above reasons and since power line technology appears to be more mature for the indoor home-networking scenario than for the outside broadband access one, focus here is on the modeling of the indoor power line channel and, in particular, on the transfer function between outlets. A new software based approach to the characterization of the indoor power line channel has been investigated and is described here.

A bottom-up approach based on the frequency-domain modeling and using scattering matrix is implemented in this paper similarly as in [4], however a two-wire line model with no effect of third conductor is used since the conductor of concern are only on which the signal propagates i.e. the 'hot' and 'return' wire. Moreover what the above paper [4] and the previous papers lacks is that the equations used for the determination of primary line parameters R, L, C and G are that which are used for low frequencies and when the distance between the conductors is very much greater than the radius of the conductor, whereas in an indoor power line network the cables are simply pulled through the conduit and lie in close proximity to each other and the technology operates at high radio frequency (MHz). This paper is organized as follows. An overview of broadband communications for substation monitoring, taking an example of transformer monitoring is discussed in Section II Also, how Broadband PLC can be integrated into the existing broadband backbone infrastructure is mentioned in this section. Section III deals with the transmission line analysis of power line Channel. Modeling of power line is done in Section IV. Transfer function characterization using software simulation is discussed in Section V while concluding remarks are mentioned at the end in Section VI.

2. Getting Substation Data Using Broadband

In the broadband scenario, control centre is a client, linked to the substation using a high speed broadband communication as shown in fig1. [2]. Substation here is the server where data is collected and maintained in a substation database which may be using data concentrator or can be multiple IED's storing data. In the broadband scenario, control centre is a client, linked to the substation using a high speed broadband communication as shown in fig 1[2]. Substation here is the server where data is collected and maintained in a substation database which may be using data concentrator or can be multiple IED's storing data.

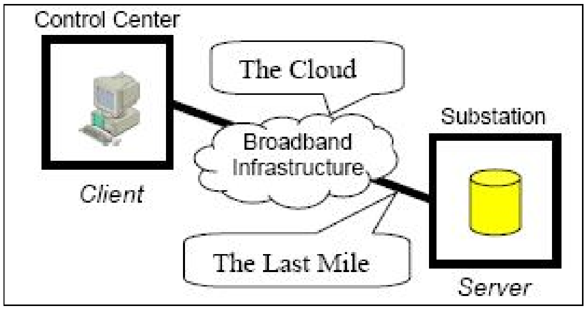


Figure 1: Client server communication architecture

Cloud represents a high speed backbone-either private or public and last mile represents the broadband connectivity to the backbone. An example showing transformer monitoring via Intranet is discussed in [9] which show the use of broadband technologies for substation monitoring as shown in fig.2 below.

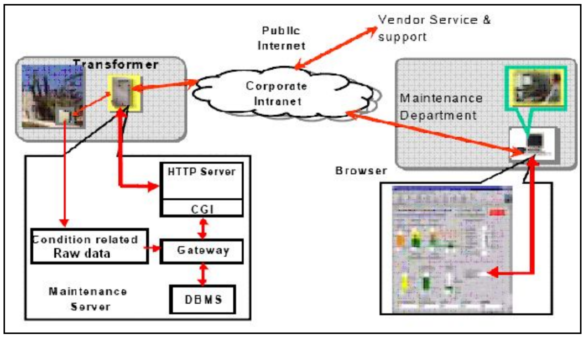


Fig.ure 2: Transformer Monitoring via Intranet

On the server side in the substation condition related raw data are retrieved from the transformer continuously in an asynchronous mode and stored in a database management system (DBMS). A CGI program can be used to access the database. CGI is the Common Gateway Interface, a technology that creates and handles dynamic documents. The client is installed on a PC in the maintenance department or on a notebook PC of the maintenance engineer. A standard browser serves as human machine interface. The utility homepage contains a button for transformer monitoring, which can only be activated by authorized personnel. If this page is called up, a Java applet is loaded which establishes the connection with the hypertext transfer transmission protocol (HTTP) server on site and the transformer monitoring page is refreshed with actual data from the server database.

Sending broadband signals over the high-voltage, long-haul lines are still too difficult and Broadband PLC is more a mature technology for the indoor networking scenario than for the outside one as already mentioned. Broadband PLC can be used for connectivity towards the low voltage control centre with other broadband communication technologies for the rest of the network like CATV (Community Antenna Television), ADSL (Asymmetric digital subscriber line), WiFi (wireless fidelity),etc as shown in fig.3 below.

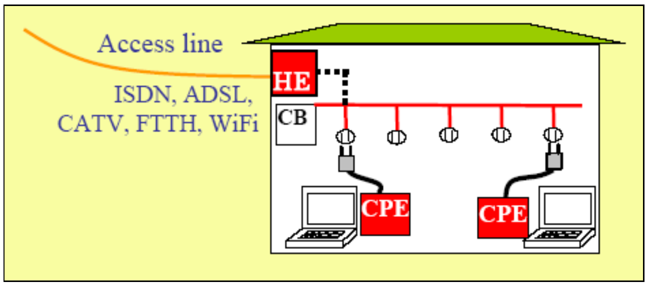


Figure 3: Broadband PLC integrated with other network ∏

In the Broadband PLC basic architecture, signals are injected into the electric network from a head end (HE) on the indoor low voltage power line at the circuit board (CB). A Broadband PLC modem (or Customer Premises Equipment –CPE) is plugged into any electrical outlet and then PC is connected to the Broadband PLC modem with an Ethernet or USB cable to finish the connection.

3. Transmission Line Analysis of Power Line

When power lines are used to transmit high frequency communication signals, they can be regarded as transmission lines, which guide the transverse electromagnetic (TEM) waves along them. According to Electromagnetic theory, the two-wire transmission line must be a pair of parallel conducting wires separated by a uniform distance. In the actual installation, the power cables are simply pulled through the conduit and the separation between them is not uniform at all. However, the conduit normally has small cross-sectional area and this limits the variation of the separation between the cables. Hence, the assumption of uniform separation is reasonable in this case. Based on the above consideration, the paired power cables are regarded as a distributed parameter network, where voltages and currents can vary in magnitude and phase over its length. Hence, it can be described by circuit parameters that are distributed over its length as shown in fig.4 below. The quantities v (z, t) and v (z + Δz, t) denote the instantaneous voltages at location z and z + Δz, respectively. Similarly, i (z, t) and i (z + Δz, t) denote the instantaneous currents at z and z + Δz, respectively. *R* defines the resistance per unit length for both conductors (in Ω / m), *L* defines the inductance per unit length for both conductors (in H/m), *G* is the conductance per unit length (in S/m), and *C* is the capacitance per unit length (F/m). Based on the lumped-element circuit of a two wire transmission line as shown above, model parameters per unit length (m) at high radio frequencies when distance 'D' between conductors is comparable to the radius 'a' of the conductor the equations for the transmission line parameters are described as below [6]:

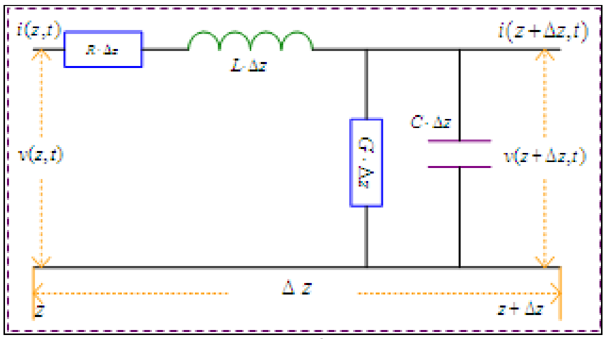


Figure 4: Equivalent circuit of two-wire transmission line

Resistance

$R = 1 / \pi \; a \, \delta \, \sigma$ (1)

Where δ = skin depth = $\sqrt{(1 / \pi \, f \, \mu \, \sigma)}$

and is a function of frequency 'f '. This effect causes an increase in the resistance of the cable and it worsens as the current frequency increases.

Also,

Inductance

$L = \mu/\pi \; [a \cosh (D / 2a)]$ (2)

Conductance

$G = \pi \; \sigma / [a \cosh (D / 2a)]$ (3)

Capacitance

$C = \pi \, \xi / [a \cosh (D / 2a)]$ (4)

Here, μ = permeability of copper conductor, σ = conductivity of the dielectric material, and ξ = permittivity of the dielectric material.

4. Modeling The Indoor Powerline

Typically, the 'hot' and 'return' cables are used as the PLC transmission channel, which can be approximated as a close form of the "two-wire transmission line". The cables are made up of stranded copper conductors with PVC insulation laid inside PVC conduits that are embedded inside the wall in an Indian residential scenario. However, here the indoor power cables are approximated to be a two-wire transmission line with solid core conductor for generalization and ease of implementation using software simulation as shown in Fig. 5. The dielectric material, between the cable conductors, is inhomogeneous in both space (due to the round shape of the cable conductor) and contents (mixture of insulation and air). But since the cables are of close proximity to each other, the thickness of the insulation 't' is comparable with that of the air space between the conductors. In this model, the dielectric is assumed to be just a mixed content material and the effects of the inhomogeneous in space are neglected to keep the model tractable.

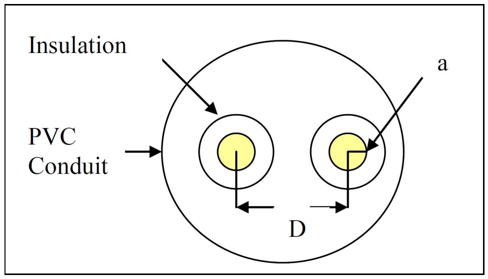


Figure 5: Approximate model of the indoor power line

Here, a is radius of conductor and distance between the two conductors (Live and Neutral) 'D'= 2t + 2t + 2a. Now, the length of transmission line is taken to be 'S'=5 m with shunt stub terminated in an open circuit as shown in fig.6 for simulation considering the fact that, indoor power lines are radial N-branched network as shown in fig.7 below.

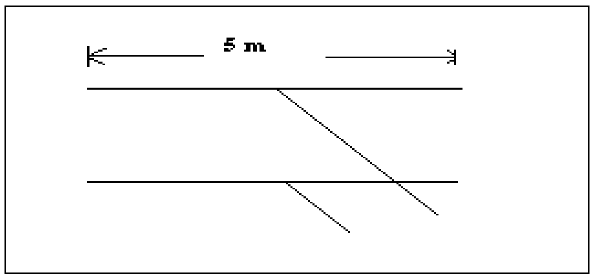


Figure 6: Configuration of simulated network

In fig.7, port 1 is the transmitter from where the signal is sent, and port 2 is the receiver where the signal strength is measured.

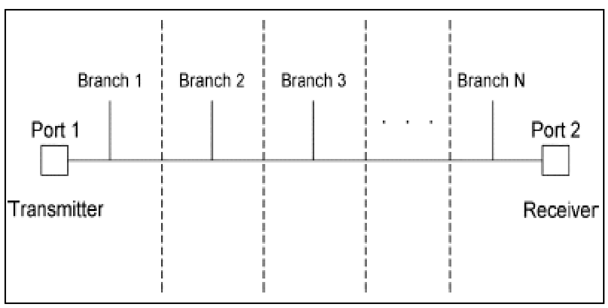


Figure 7: A simplified indoor power line channel

5. Transfer Function Modeling

The main causes of attenuation in a power line network is due to the heat loss and radiations along the power line, reflections arising from the points of impedance discontinuities on the propagation channel causing destructive interference and due to the forward propagating wave falling out of phase with the main incident forward wave. Frequency-domain modeling approach using scattering matrix technique accounts for all these reflected and delayed paths in the power network. S-parameter matrix gives relationship between reflected (b) and incident (a) power waves as described below for a two port network.

$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} \quad (5)$$

Here, S_{21} gives the Network Transfer Function.

Software simulation using MATLAB is done to obtain the transfer function whose magnitude (dB) versus frequency plot gives the attenuation in the signal strength and angle (radian) versus frequency plot gives the phase distortion or delay as shown in fig.8 and fig.9 respectively.

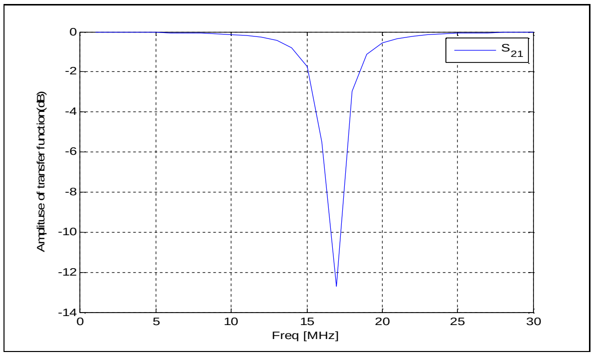


Figure 8: amplitude of Transfer function

Fig.8 shows the presence of deep notches at certain frequencies in the transfer function. For communication to establish between two access points, the carrier frequency chosen must not fall at deep notches.

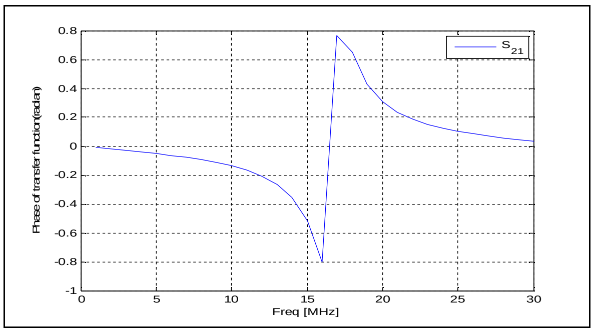
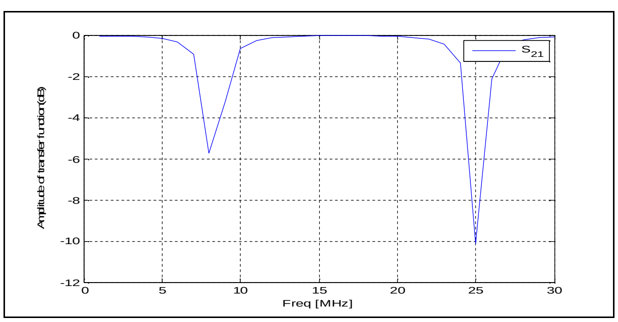


Figure 9: Phase of Transfer function

Also, Fig.9 shows that when there is deep notch at certain frequency in the transfer function, there is a discontinuity in the phase characteristics leading to phase distortion or delay.

6. Effect of Line Length

To see the effect of line length on transfer function of the modeled power line channel In this simulation the cable length was increased by 5 meters i.e. from l=5 m to l=10 m. The results are shown in Figure that numbers of notches are increased from one to two and amplitude of attenuation also increased. Therefore signal are effected due to attenuation, substation monitoring are effected deduces the attenuation increases with increase in length [3]. From the above four graphs it is observed that when the transmission line length (length of transmitter and receiver) was increased, correspondingly the distortion along with the signal attenuation at the receiving end was increased. Hence the data communication in the transmission lines is applicable for shorter distances or it can be applied for longer distance with more number of repeaters [3].



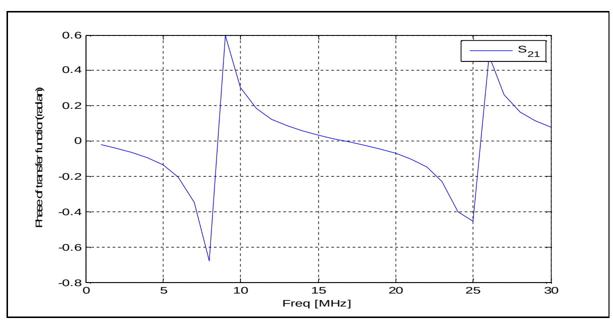


Figure 10: amplitude of of Transfer function *Figure 11: Phase of Transfer function*

7. Conclusion

It is seen that Broadband PLC offers an exciting opportunity for applications like substation automation using low voltage indoor power line. The low voltage single-phase power line is modeled as a two wire transmission line and the channel transfer function is determined using scattering matrix. Model can predict the channel transfer function of the PLC medium including the position of attenuation notches and the accompanying phase distortion or delay.

8. References

1. C W Gellings and K George, "Broadband over power lines 2004: Technology and Prospects", Electric Power Research Institute (EPRI), USA, Oct 2004.
2. D Proudfoot, "Information Technologies for Substation Automation Applications", Proc. of IEEE on power delivery, 2001, pp 349-361.
3. H. Hrasnica, A. Haidine, and R.Lehnert, Broadband Powerline Communivations. London, U.K.: Wiley, 2004.
4. H. Meng, S. Chen, Y. L. Guan, C. L. Law, P. L. So, E. Gunawan, and T. T. Lie, "Modeling of transfer characteristics for the broadband power line communication channel," IEEE Trans. Power Del., vol. 19, no.3, Jul. 2004, pp. 1057–1064.
5. J Anatory, M M Kissaka, and N H Mvungi, "Channel model for broadband power line communication," IEEE Trans. Power Del., vol.22, no.1, Jan. 2007, pp. 135-141.
6. Ludwig, Reinhold and Pavel Bretchko, RF Circuit Design: Theory and Applications, Prentice-Hall, 2000.
7. S. Galli and T. Banwell, "A novel approach to the modeling of the indoor power line channel-part II: Transfer function and its properties," IEEE Trans. Power Del., vol. 20, no. 3, Jul. 2005, pp. 1869–1878.
8. V C Gungor and F C Lambert, "A survey on communication networks for Electric system automation", ELSEVIER Journal of computer networks 50(2006), pp 877-897.
9. Volker Lohman, "New strategies for substation control, protection and access to information", CIRED 2001, Amsterdam