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저압 PLC 배전 네트워크를 위한 두가지 전송 주파수 대역 비교

김용성*, 김재철*, 권영목*, 이양진*
숭실대학교*

Comparison of two different frequency bands on LV distribution network for PLC

Young Sung Kim, Jae-Chul Kim, Young-Mok Kwon, Yang-Jin Lee
SoongSil University

Abstract - This paper describes the comparison of Two frequency ranges for power line communication. The first one is that the frequency range from 100 to 400 KHz is supported by the Federal Communication Committee(FCC). The other one is that the frequency range from 1MHz to 30MHz is based on the European-supported EN5006A band. In this paper, the advantages and disadvantages of their frequency ranges are discussed for PLC. By ATP/EMTP software, the signal attenuation is simulated both the frequency ranges. It shows that the signal attenuation is bigger at high frequency than at low frequency.

1. Introduction

PLC(Power Line Communication)technologies which become the center of attention utilize the distribution grid to deliver high speed data. For a decade, Those technologies have used in the only communication among the distribution stations in a narrow band. Recently, demands for high speed communication are increasing, for instance, home networking businesses, security systems, network switching, network monitoring, demand side management of power distribution networks, remote load control, meter reading telemetry and multimedia[1][2]. For these reasons, the broadband power line communication is appropriate to be applied. In addition, the higher frequencies are required to obtain wide band. There are attractive advantages using the metropolitan power distribution grid for combination of the power network within the home or office. One of the most important merits is that no additional wires need to be installed.

There are two frequency bands are discussed for PLC. The first one is that the frequency band from 100 to 400 KHz is supported by the Federal Communication Committee(FCC). The other one is that the frequency band from 1MHz to 30MHz is based on the European-supported EN5006A band. In this paper, we divide three parts to discuss PLC distribution line. In section(2.1), skin effect of distribution line is described in detail. In 2.2 the model of PLC distribution line. Lastly, in 2.3, by ATP/EMTP software, signal attenuation of PLC distribution line is simulated at frequency range from 100KHz to 400KHz and from 1MHz to 30MHz.

2 Calculation of distritution line parameters

2.1 Skin effect Resistance

The properties of cables and wires are considered as a form of transmission line. For the low frequency of power transmission, the only parameters that tend to be considered are the capacitance per length, inductance per length, and their relationship. However, when we transmit alternating signals along conductive lines, we may experience the alternating current flow mostly near the outer surface of a solid electrical conductor, at high frequencies. these effects are generally called 'skin effects'[3].The effect becomes more and more apparent as the frequency increases.

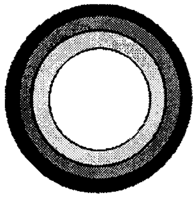

Fig.1. Assumed current density

2.1.1 The Resistance of distribution line

The degree to which frequency affects the effective resistance of a solid wire conductor is impacted by the gauge of that wire. As a rule, large-gauge wires exhibit a more pronounced skin effect (change in resistance from DC) than small-gauge wires at any given frequency. The equation for approximating skin effect at high frequencies (greater than 1 MHz) is as follows

$$R_{AC}=(R_{DC})k\sqrt{f} \qquad (1)$$

R_{AC} is AC resistance at given frequency f, R_{DC} is Resistance at zero frequency, k is wire gage factor, f is frequency of AC in MHz. In detail, It is normal to assume that all the current flows within the "skin depth" of the wires. The well-known equation is for skin depth given below. Note that skin depth (δ) is a function of only three variables, frequency (f), resistivity (ρ), permealbility constant(μ_0) and relative permeability (μ_r)

$$\mu=\mu_0\mu_r$$

$$\delta=\sqrt{\frac{2\rho}{2\pi f\mu_0\mu_r}} \qquad (2)$$

$$R_s=\frac{\rho}{\pi a\delta} \quad (\Omega/m) \qquad (3)$$

$$X_r=[\cos^{-1}(\frac{r_{wire}-\delta}{r_{wire}})\times r_{wire}^2-(r_{wire}-\delta)\sqrt{r_{wire}^2-(r_{wire}-\delta)^2}]/(2\times r_{wire}\times\delta) \qquad (4)$$

where r_{wire} is the radius of a single wire in the conductor and δ is the skin depth above equation (2). With this factor, the final resistance for the distribution wire is as follows

$$R=X_r\times R_s \quad (\Omega/m) \qquad (5)$$

2.1.2 Inductance and Capacitance of distribution line

the inductance of the two-wire transmission line includes the self-inductance for each conductor and the mutual inductance between them. L_s is self-inductance for one conductor and L_m is mutual inductance between a pair of parallel conductors D is the distance between conductors and L total inductance is as follows

$$L_s=\frac{\mu}{8\pi} \quad (H/m) \qquad (6)$$

$$L_m=\frac{\mu}{\pi}\ln(\frac{D-a}{a}) \quad (H/m) \qquad (7)$$

$$L=2L_s+L_m=\frac{\mu}{\pi}[\frac{1}{4}+\ln(\frac{D-a}{a})] \quad (H/m) \qquad (8)$$

2.2 The model of PLC line

All network parameters relate total voltages and total currents at each of the two ports. These network analysis methods are theoretically useful at low frequencies but some problems arise, when the frequencies move to higher as range from 1Mhz to 30 Mhz. For instance, Equipment is not readily available to measure total voltage and total current at the ports of the network. In addition, short and open circuits are difficult to achieve over the broad band of frequencies. Therefore, critical method is necessary to solve these problems. In this paper, traveling wave is applied to approach network characterization rather than total voltages and currents .Fig.2 show the traveling wave behavior at high frequencies. In both directions along this transmission line, voltage, current and power should be described as the form of waves traveling when source impedance and load impedance are mismatched ($Z_S\neq Z_L$)

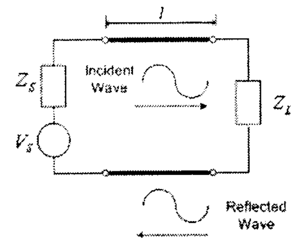

Fig.2. reflected wave of power line

The two intrinsic line parameters for the transmission line such as the propagation constant γ and the characteristic impedance Z_0 can be written as[5][6].

$$\gamma=\alpha+j\beta=\sqrt{(R+j\omega L)(G+j\omega C)} \qquad (4)$$

$$Z_0=\sqrt{\frac{R+j\omega L}{G+j\omega C}} \qquad (5)$$

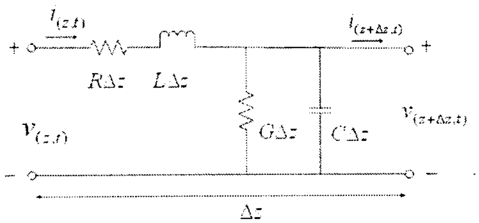

Fig.3. two-wire transmission line model

At each point of the transmission line voltage and current can be written as

$$V_{(Z)}=V_0^+e^{-j\beta Z}+V_0^-e^{+j\beta Z} = V_0^+(e^{-j\beta Z}+\Gamma e^{+j\beta Z}) \qquad (6)$$

$$\Gamma=\frac{V_0^-}{V_0^+} \qquad (7)$$

$$I_{(Z)}=\frac{V_0^+}{Z}(e^{-j\beta Z}-\Gamma e^{+j\beta Z}) \qquad (8)$$

2.3 Scattering network in PLC

The additional traveling waves are recognized in Fig 4. There are interrelation between the incident waves and reflected waves. Two port net work could be applied by this characterization.

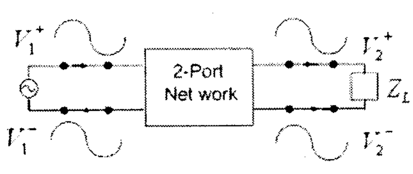

Fig.4. Traveling waves of 2-port network

relation between the incident waves and reflected waves could be written as[7]

$$V_1^-=S_{11}V_1+S_{12}V_2$$

$$V_2^- = S_{21} V_1^+ + S_{22} V_2^+ \quad (9)$$

The appropriate representation is called the scattering matrix and scattering parameters[8].

$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix} \quad (10)$$

$$S_{11} = \left. \frac{V_1^-}{V_1^+} \right|_{V_2^+ = 0} \qquad S_{22} = \left. \frac{V_2^-}{V_2^+} \right|_{V_1^+ = 0}$$

$$S_{12} = \left. \frac{V_1^-}{V_2^+} \right|_{V_1^+ = 0} \qquad S_{21} = \left. \frac{V_2^-}{V_1^+} \right|_{V_2^+ = 0} \quad (11)$$

2.4 ATP/EMTP simulation

This part describes a method that permits to evaluate PLC attenuations in the distribution line including both KHz band and MHz band. As Fig 5, the distribution line for PLC is model base on Fig 3.

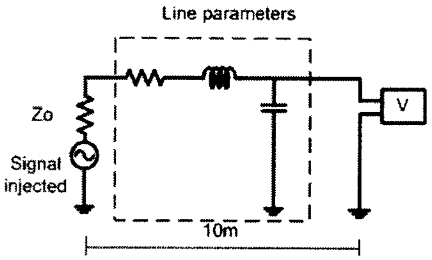

Fig.5. The model of transmission line ATP/EMTP simulated

The Injected voltage amplitude is 1mV. The following formulas are used to calculate the attenuation on the distribution line:

$$\text{att} = 20 \log\left(\frac{V_{out}}{1mV}\right) \ [dBm]$$

Fig 6 shows results of the attenuations at frequency range from 1MHz to 30MHz. The attenuations are greatly increasing as frequency increases.

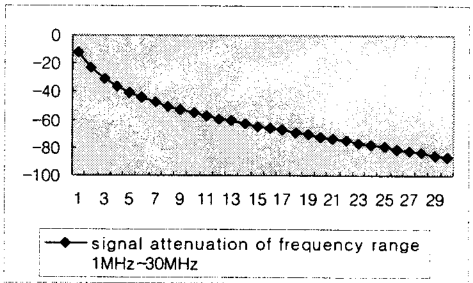

Fig.6. Attenuation of frequency range 1MHz~30MHz

Fig 7 shows results of the attenuations at frequency range from 100KHz to 400KHz. The attenuations are increasing as frequency increases but compare to Fig6 attenuations are increasing slightly.

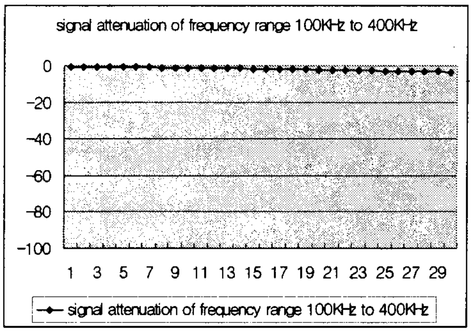

Fig 7 Attenuation of frequency range 100KHz ~400KHz

3. Conclusions

This paper carries out the simulation of attenuation characteristic on the distribution line. The frequency ranges are from 100 to 400 KHz and from 1MHz to 30MHz. The results show MHz bands have bigger signal attenuation than KHz bands. However, KHz frequency bands are more sensitive than MHz frequency bands. In reality, It depends on case by case.

Acknowledge

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[Reference]

[1] Klaus Doster, *"RF-Models of the electrical Power distribution Grid"*,International Symposium Power line communication and its applications, pp105~111, March,1998.

[2] Arthur R. Bergen, Vijay Vittal *"Power Systems Analysis"* Prentice-Hall,Inc, second edition,pp294~322, 2000.

[3] H.Meng,S Chen, Y. L Guan, C.L Law P.L.So,*"Modeling of Transfer Characteristics for the Broadband Power Line Communication Channel"*, IEEE transactions on power delivery, VOL.19, NO.3, pp1057~1064,July,2004.

[4] Manabu Sekizawa and Yasuo Yahagi, *" Developmet of High Speed Communication System Using Power Distribution Line Carrier"* International Symposium Power-line communication and its applications, pp158~173, March 1998.

[5] Guillermo Gonzalez *"Mircowave Transistor Amplifiers Analysis and Design"* Prentice Hall, second edition, pp1~20, 1997.

[6] Matthew M. Radmanesh *"Radio Frequency and Microwave Electronics"* Prentice Hall PTR, pp193~ 278, 2001.

[7] T. Satenaer and P. Delogne, *"Power cables modeling for broadband communication,"* in Proc. 5th Int. Symp. Power-Line Communications and its Applications (ISPLC2001), April.2001..