Characteristic Impedances in Low-Voltage Distribution Systems for Power Line Communication

Young-Sung Kim* and Jae-Chul Kim†

Abstract - The input and output impedances in a low voltage distribution system is one of the most important matters for power line communication because from the viewpoint of communication, the attenuation characteristic of the high frequency signals is greatly caused by impedance mismatch during sending and receiving. The frequency range is from 1MHz to 30MHz. Therefore, this paper investigates the input and output impedances in order to understand the characteristic of high frequency signals in the low voltage distribution system between a pole transformer and an end user. For power line communication, the model of Korea's low voltage distribution system is proposed in a residential area and then the low voltage distribution system is set up in a laboratory. In the low voltage distribution system, S parameters are measured by using a network analyzer. Finally, input and output impedances are calculated using S parameters.

Keywords: Characteristic impedance, Distribution system, Modeling of PLC, Power line communication

1. Introduction

In order to meet the demands of today's customers, every component is connected to the network for ease and convenience, creating ubiquitous systems. PLC (power line communication) is one of the most adequate communication systems for the ubiquitous world because it offers several advantages. PLC is available worldwide in a very large number of components because it reaches most components that require electric power. Also, it offers great opportunity for cost-effective telecommunication networks without the construction of new cable. Additional building costs are not entailed because PLC uses electrical power supply networks for communication purposes.

Telecommunication systems have developed rapidly while customers require high data rates of communication that are low in price. Demands for high speed communication are increasing, for instance home networking businesses, security systems, network monitoring, remote load control, meter reading telemetry and so on. Therefore, only home networks are insufficient but power line communication systems are extended. It is very essential that home electrical power supply networks be connected to a back bone so a low voltage distribution system is used for extension of networks. Particularly, the low-voltage distribution system between a pole transformer and end user is discussed.

However, electrical supply networks are not designed for telecommunication, so there are some obstacles such as noise and signal attenuation. In this paper, the factors of attenuation are mostly discussed, especially impedance mismatch [1]. Sending and receiving information at a higher rate needs a wider bandwidth. Several recent researches suggest the frequency range from 1Mhz to 30Mhz in order to establish high-speed packet-based communication systems [2, 3]. Therefore, the problems of signal attenuation are concerned at high frequencies. The propagation and the attenuation of high frequency carrier signals rely heavily on the power line structure. The power line structure consists of various types of wires. Therefore, the impedance mismatch, which is produced by different thicknesses of wires, is highly significant.

Kim in [4] investigates the characteristics of attenuation by actual measurements in the home and at the office. Philipps in [5] analyzes the characteristic impedance by actual measurements using a network analyzer at a university building and a single family dwelling. Park in [6] investigates indoor low voltage power line impedance. However, those papers only discuss the characteristic attenuation or the characteristic impedances within the home and within the building. In this paper, the characteristics of the low voltage distribution system are investigated from a pole transformer to a watt-hour meter of the end user, which has not been discussed. The electrical and impedance characteristics of electric power circuits are very complicated to analyze. Therefore, it is only realistically understood by actual measurements of high frequency signals. First of all, the low voltage system

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is modeled form Korea's distribution system in residential areas for power line communication. In detail, the type of wires and thickness are considered but description of the complex power system is simplified. Secondly, the low voltage distribution system is built at a laboratory building for an experiment. Thirdly, measurements of S parameters, which are reflected coefficients and transmission coefficients, are carried out on the low voltage distribution system. From the results of experiments, the input and output impedances are calculated by using S parameters.

2. Input and Output Impedances

In this paper, the traveling wave is applied to approach network characterization rather than the total voltages and currents. An incident wave encounters a second medium different from the first. It is partly reflected while the remainder is transmitted through. That phenomenon creates a reflected wave and a transmitted wave. Fig. 1 shows reflection phenomenon. The ratio of the reflected wave to the incident wave is called reflection coefficient [7]. When the incident wave encounters a second medium such as a termination or a discontinuity, in the special case of a uniform transmission line, then under theses conditions, the ratio of the reflected wave to the incident wave is the reflection coefficient Γ.

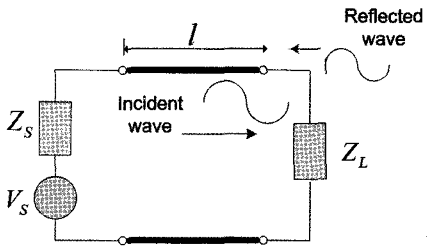


Fig. 1. The reflection at connection

At any point along the transmission line the relation between input impedance and reflection coefficient is generally described as Equation (1).

$$Z_{in} = Z_0 \frac{Z_L + Z_0 \tanh \gamma l}{Z_0 + Z_L \tanh \gamma l} \quad (1)$$

Z_{in} : input impedance Z_0 : characteristic impedance

Z_L : load impedance γ : propagation constant

l : line length

At the source end or the load end, the input impedance is described as Equation (2). The input impedance is obtained if reflection coefficient is known.

$$Z_{in} = Z_0 \frac{1+\Gamma_{in}}{1-\Gamma_{in}} \quad (2)$$

Γ_{in} : input reflection coefficient

The high frequency S parameters are used to characterize the two-port system at high frequency. These parameters are based on the concept of traveling waves and provide a complete characterization of any two-port system under analysis or test at high frequency [8]. Fig. 2 shows the two- port with incident and reflected waves at each port.

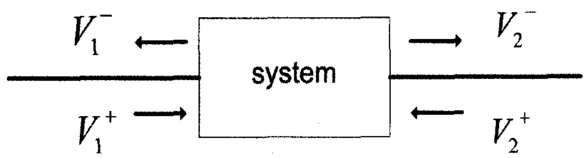


Fig. 2. The two-port system

To define the S-parameters accurately, we will consider the incident voltage V_i^+ and reflected voltage V_i^- from the terminal. The scattering parameters are defined to describe the linear relationship as in Equation (3).

$$V_1^- = S_{11}V_1^+ + S_{12}V_2^+$$
$$V_2^- = S_{21}V_1^+ + S_{22}V_2^+ \quad (3)$$

S_{11} is input reflection coefficient. Therefore, S-parameters are substituted for reflection coefficient as in Equation (4).

$$Z_{in} = Z_0 \frac{1+S_{11}}{1-S_{11}} \quad (4)$$

3. Modeling of LV Distribution System

In the residential area, the number of customers connected to the system depends on the capacity of pole transformers. There are different types of transformer connections. Those affect the configuration of low-voltage distribution systems greatly. In this paper, the low-voltage system between a pole transformer and end user is the focus. Fig. 3 shows typical low-voltage distribution systems in Korea. The low-voltage distribution system is a tree type of system. From the general low-voltage distribution network, only one customer is chosen and the configuration is described in detail because entire systems are very complicated to analyze in regards to the characteristic of power line system. In other words, only one customer is considered as the simplest system to analyze the characteristics of system.

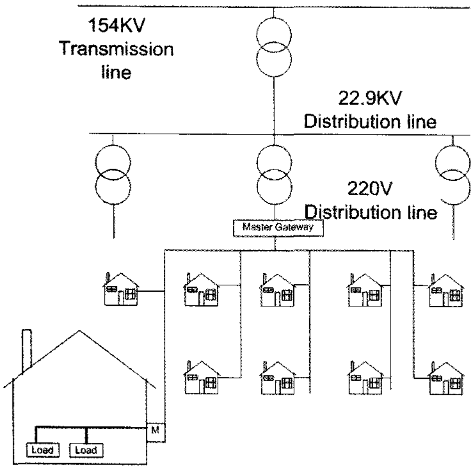


Fig. 3. Typical Korean distribution system

Fig. 4 describes configuration of the low voltage distribution system in detail. Each line has to be modeled with resistance, capacitance, and reactance as a lumped circuit. However, if the modeling of the line includes those parameters, it is hard to understand the model. Therefore, the line model is simplified with the block diagram shown in Fig .5.

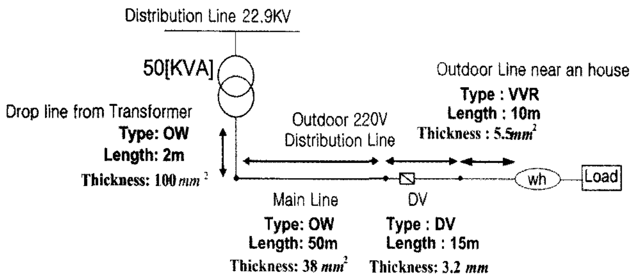


Fig. 4. Description of low voltage system in detail

Each block includes resistance, capacitance, and reactance. The J represents the junction between two different wires. The power fuse is located between OW wire and DV wire.

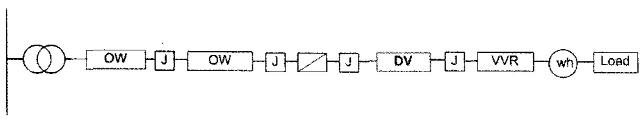


Fig. 5. Model of low voltage system

The model of low voltage distribution system simply explains various wires and junctions for power line communication because the reflection obviously occurs at the junction points. At high frequencies, the signal attenuation phenomenon in power systems results not only from the loss proportional to the line's length, but also from the loss at the connections [9]. However, the construction of power lines cannot be adjusted or changed for PLC. Therefore, we only consider the injection point and receiving point of the signal. To avoid less signal attenuation, impedance is matched when the signal is injected to networks or received. In advance, S parameters are measured from the experiment to obtain input or output impedances.

3. Experiment and Results

In the low voltage distribution system, the power line communication can only be realistically understood by actual measurements of the high frequency signal. The low voltage distribution system is constructed at a laboratory building as in Fig .6.

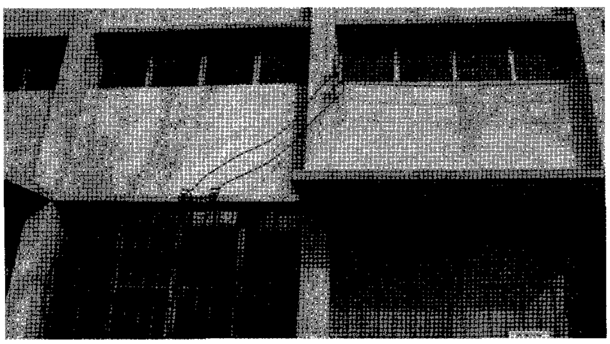


Fig. 6. Low voltage distribution system at lab

At frequency range from 1MHz to 30MHz, the S parameters are measured with Network Analyzer 8712ES from the pole transformer and the watt-hour meter located at an entrance of the house. Fig. 7 shows how to measure S parameters at input and output.

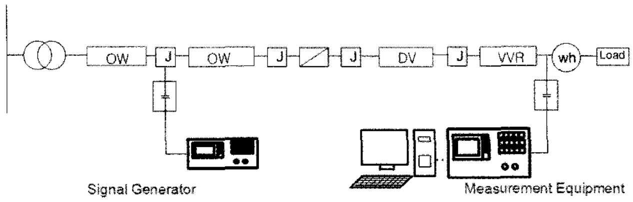


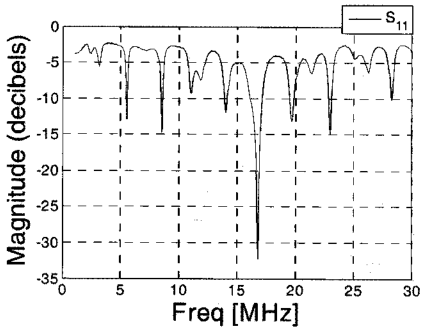
Fig. 7. Measurement Condition

We perform the experiment with various loads. Table 1 shows the different load connection. The first experiment is that S parameters are measured with no load. The second experiment is that the parameters are measured with a heater. The third experiment is with a heater and a refrigerator. The last experiment is that the parameters are measured with a heater, a refrigerator and dryer. Using the reflection coefficients of S parameters, the input and output impedances are finally found.

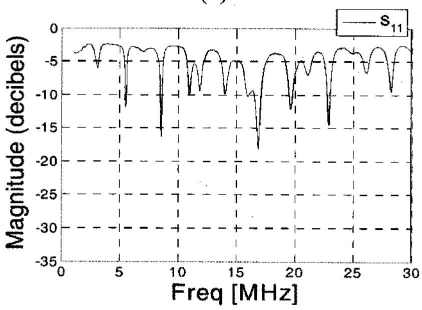
Table 1. Experiment of load difference

NO. of experiment	Load type
1	Empty
2	Heater
3	heater + refrigerator
4	heater + refrigerator +dryer

From the tests, all S parameters are measured using a Network Analyzer. Fig. 8 shows the input reflection coefficients with various load connections.



(a)



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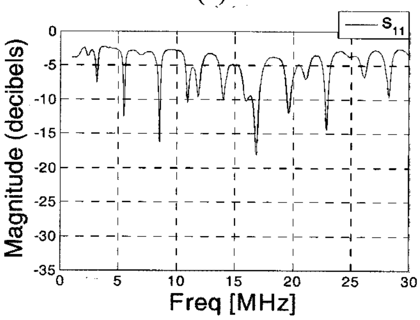

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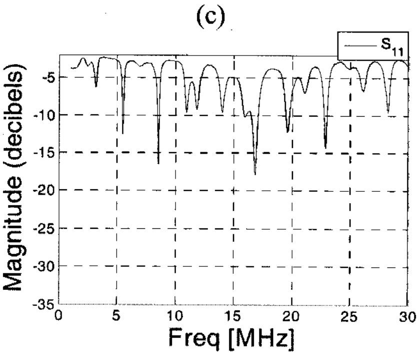


(d)

Fig. 8. S_{11} parameters from the experiments

In Fig. 8, (a) is S_{11} with no load, (b) is with a heater, (c) is with a heater and a refrigerator, and (d) is with a heater, a refrigerator and a dryer. According to the results of the test, S_{11} is not much affected by the loads.

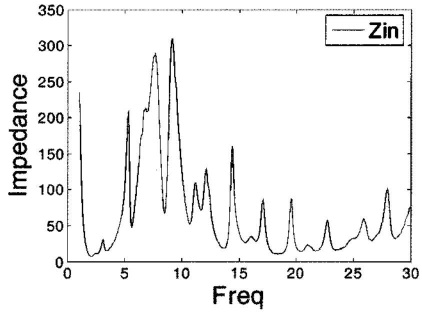
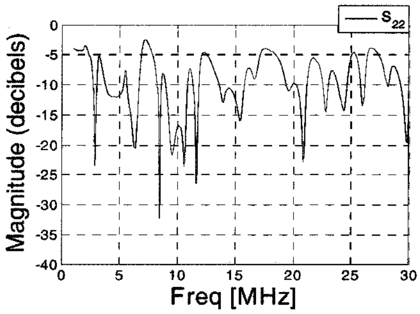
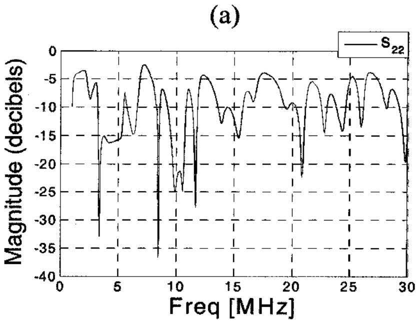


Fig. 9. Input impedance

In Fig. 9, the characteristic impedances are obtained by calculation of S_{11} from equation (4) in the frequency range 1MHz to 30MHz. The impedance at frequency range 1~15MHz is bigger than the impedance at frequency range 16-30MHz.



(a)



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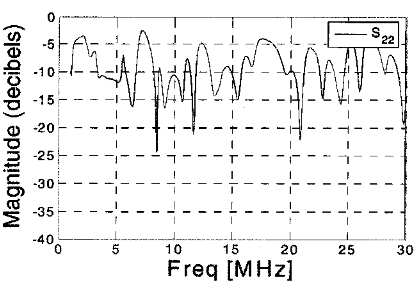

(c)

Fig. 10. S_{22} parameters from the experiments

In Fig. 10, (a) is with a heater, (b) is with a heater and a refrigerator, and (c) is with a heater, a refrigerator and a dryer. According to the results of the test, S_{22} is slightly affected by the loads especially in the frequency range of 1MHz ~15MHz.

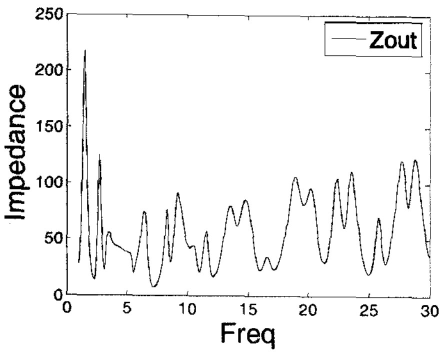

Fig. 11. Output impedance

In Fig. 11, the characteristic impedances are obtained by calculation of S_{22} parameters from Equation (4) in the frequency range of 1MHz to 30MHz. It shows the range of impedances with various frequencies. From the results, the impedance is slightly fluctuated by load variation.

5. Conclusion

For power line communication, the input and output impedance in a distribution system is one of the most important matters at modem connection. From the viewpoint of communication, the attenuation characteristic of the high frequency signals is greatly caused by impedance mismatch. Therefore, this paper investigated the input impedances at point of injection in order to analyze the attenuation characteristic of high frequency signals in the low voltage distribution systems, and output impedances as well. For evaluation of the input and output impedances, the modeling of the low voltage distribution system was proposed. For modeling, the general distribution system was researched. The components and line structure have been accurately described. Moreover, experiments were performed on the low voltage distribution system model.

The important results of this paper are summarized as follows:

1) For power line communication, the modeling of the low voltage distribution system was described in the section between the pole transformer and the consumer. In the residential area, the typical Korea low voltage distribution system was applied to the modeling.
2) The experimental set-up of the low-voltage distribution system model was built at the laboratory building. The reflection coefficients were examined by using a network analyzer. From the results of the experiment, the input and output impedances were found by calculation of the reflection coefficients.

It is expected that the low voltage distribution system model could be used as a primary model to analyze more diverse and complex distribution systems. In addition, the obtained input and output impedances of the system from the tests provides essential information for improving the channel condition. It is worthwhile to provide the characteristic of the distribution system for the best PLC channel condition.

Acknowledgements

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