Effects of Surge Protection Devices on Performances of PLC Systems

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Abstract

This paper discusses the application and the effect of the electric surge protection device (SPD) in the power line communication channel. The comparative analysis of the effect is carried out based on the performance of the power line communication (PLC) system. The SPDs used for the laboratory experiment are categorized into different types of classes depending on the surge protection level. Various combinations of the SPD with different classes are tested to accommodate the real field environment. The transmission line length is also considered as a test parameter. The OFDM based data transmission system is assumed for the data throughput performance test for given channel conditions. Experiment results show that the effects on the PLC network vary depending on classes and locations of the installed SPDs as well as the channel length between the transmitter and the receiver end. The result confirms that systematic SPD installation requirements should be set up to maintain the stable performance of the data transmission system and the SPDs which coexist in the same power transmission lines

Keywords: *Data transmission, power line communication, SPD, varistor*

1. Introduction

Power line communication is the technology for the data transmission over the electric power transmission line where the power delivery normally utilizes limited ranges of frequency band (50~60Hz). The information signal is first modulated suitable for the electricity lines and propagated through the higher frequency band to the destination. This data transmission technology is now being adopted for various application areas including home area network, advanced metering infrastructure and internet access. These services utilize the existing electric power grid infra structure without extra installation of the wireline or wireless networks. Due to this inherent characteristic of the network every electric device connected to the electric line is potentially user equipment terminal once it is equipped with communication modules. In other words all the devices can be controlled and they are able to communicate each other through the power lines. More service areas are being developed as the smart grid becomes an essential infra structure for the near future. The ultimate goal is to manage the electric energy resources in an efficient manner from the generation to consumption.

Conventionally the power line communications are categorized into narrow band and broadband applications depending on the frequency band and the required data rate. Some of

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application areas in narrow band case include building and home automation. This application requires the data rate of several kilo-bits per second in 9 ~ 450kHz band. With this system it is possible to implement the low speed control and the voice data communication. Due to this characteristic the system is generally called low speed or low frequency band power line communication. The other category supports the data rate from a few mega bits to even hundreds of mega bits which is normally called broadband communication. The high quality voice and multimedia data can be supported with this scheme in the frequency band of 1.7 ~ 30MHz. The broad band system is normally called high-speed or high frequency band power line communication. Depending on the usage environment the system can also be categorized into the in-home and the outdoor access network. Some of the main applications of in-home network include home network and building automation system based on the low voltage power distribution cables. The access network could be built in the high, the medium and the low voltage systems. However commonly used networks are based on the medium and the low voltage systems. The first network is defined by the transmission line carrying medium voltage electric power and the related transformer subsystems. On the other hand low voltage outdoor communication utilizes the transmission lines from the pole transformer to the electricity meter for the subscriber. Different definitions exist for voltage level categorization. For example, the high voltage is defined as over 7kV, medium as 600V~7kV, and low as below 600V in Korea. The transformer located at the boundary of each voltage zone is designed such that the frequency contents around 50~60Hz are easily transmitted to improve the power delivery efficiency while the higher frequency signal is relatively decayed in large scale. This suggests that the layered architecture should be considered in the design stage of the communication network over power lines as shown in Figure 1 [1, 2].

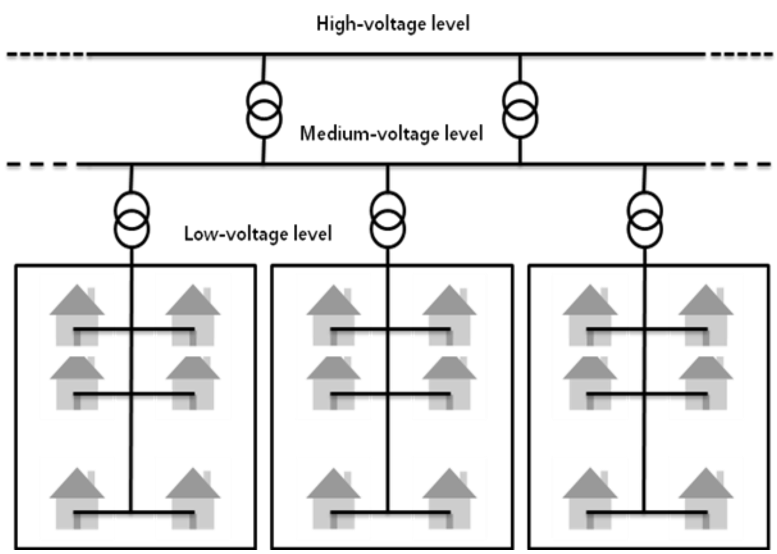

Figure 1. Access networks of power line communication for corresponding voltage level

The recent trend in the power line communication is to transmit high data rate information which requires broadband frequency band and more sophisticated data delivery techniques. The multimedia communication, internet access and smart grid data networks over power-lines are some of the representative application examples. In general broadband communication requires more channel bandwidth which is more vulnerable to multipath propagation effects. These high data rate systems are affected by severe inter-symbol interference due to the frequency selective fading. In the broadband power line communication channel this fading is closed related to the impedance of load connected with the power system. There exist various types of interferences other than the fading mentioned above which include the background noise, the impulsive noise and narrow band jamming interference from the devices connected in the same network. Another challenge for the broad band power line communication is the decreasing gain in the higher frequency region. Depending on the channel characteristics the optimized selection for the data transmission technique is crucially important to achieve the best performance under the given environment.

The orthogonal frequency division multiplexing (OFDM) scheme is one of the most promising solutions for the broadband communication systems. This technique is based on the multicarrier modulation which is already adopted in many data transmission standards for the digital communication and broadcasting systems. Some of examples include digital audio broadcasting (DAB), digital video broadcasting for terrestrial application (DVB-T), wireless local area networks (IEEE 802.11) and broadband power line communication (Homeplug). The advantage of the OFDM when it is applied to the power line channel is that this system can combat the various types of narrow band interferences utilizing the subcarrier based data delivery. While the single carrier system achieves higher data rate by squeezing the interval of one symbol period, the multicarrier aggregates the squeezed multiple symbols into one longer period of time. In the OFDM case the frequency domain is sub-divided into multiple narrow band subcarriers which contain independent data streams transmitted in parallel. This parallel transmission is possible due to the orthorgonality between all subcarriers. The advanced error control coding and interleaving techniques are usually combined with the OFDM system to enhance the performance under the noise and interference environment. Redundancy added in the original data to increase the connectivity between the information data which is useful when some of the error occurs during the transmission process. Also interleaving helps the consecutive errors to be spread into wider range of the data stream which makes the error seem to be sporadic instead of burst in a short range. The resistance to the multi-path fading and easy implementation of the channel equalization is another advantage of the OFDM systems. This is because the equalization for single carrier system in a highly frequency selective channel is known to be quite complex which might be a burden in the high speed data processing circuit design.

Surge protection devices (SPD) are installed to protect the electronic system consisting of various types of electrical loads from the disorder of electricity. The ZnO type varistor is one of representative SPDs widely installed in the field. The voltage to current characteristic shows the non-linear relationships where the internal resistance decreases as the applied input voltage increases [3]. When this device is applied in parallel to the target circuit system the transient high voltage input is by-passed to the SPD to protect the system.

The SPD is categorized into three kinds depending on the lightning protection level. The regions are illustrated in Figure 2 where three zones are labeled as LPZ1, LPZ2 and LPZ3 which are associated with the level 1 through 3, respectively. This class level determines the location of installation in the power transmission system [4-5]. For each zone appropriate level of SPDs should be installed to protect the electric devices from the lightening. In general higher SPD level limits the surge current in more strict condition. Recently, related technical standards are being developed in Korea which mandates the installation of SPD at the power distribution system. This provision necessitates thorough evaluation of the effect of the SPD on the communication channel which might be embedded in the power line.

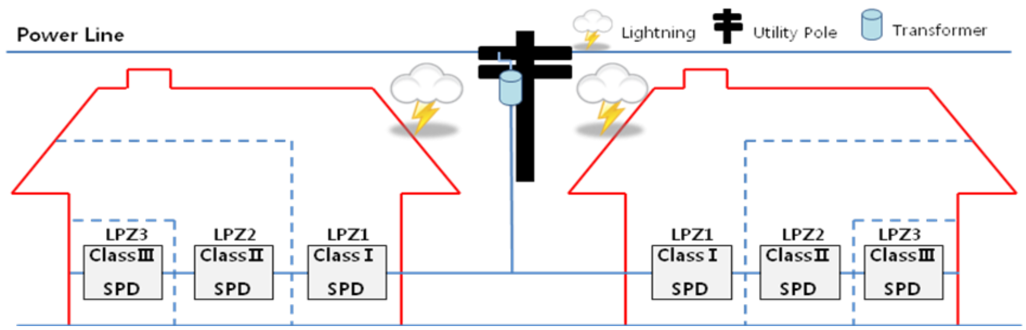

Figure 2. Lightning protection zones and applications of SPDs

As mentioned above in brief the application of the SPDs in the power line may change the characteristics of transmission channel. The energy storing component which might be capacitive and/or inductive affects the shape of the transmission function between the transmitter and receiver in the data transmission network based on the power line communication. Related research works already show the impact of SPDs on the power-line communication. It is also known that the varistor is related to the loss of transmission of power line communication [6]. However, more quantitative analysis needs to be studied due to SPD's grade level and the power line length. This can help to predict the effect of the installation and further more to find out the cause of the performance degradation. This paper discusses the experiment results which measures data rate performance under the selective combination of SPD and channel lengths.

In the next section system model is discussed for the experiment. Simulation results are discussed for the data rate as a function of channel environments which include the class of SPDs and the transmission lines. Concluding remarks follow at the end.

2. System model and performance measurements

The test system is composed as in Figure 3 for varying power line lengths (1 m, 50 m and 100 m). Lightning protection zones (LPZ1, LPZ2 and LPZ3) are also shown at the transmitting and the receiving end, which are located in the routes of data transmission of the power-line communication system. The power of single phase 220V is assumed to be supplied and the OFDM based high-speed power line communication modem for single phase was selected to use [7~9]. Notebooks are installed to generate the data and to monitor the transmission data rates. The electric power supplied to the notebook is isolated from the test system to reduce impacts of changes in load impedance which is related to the channel spectrum shapes.

The ground-type surface plug receptacles are used for classification of SPD by grade. In addition, the ground-type plugs are connected to the voltage-limiting varistor in the SPD by Class I, II, and III. Two high-speed power-line communication modems are connected to each notebook, respectively. One end sends the data (Tx) and the other receives data (Rx). There are a total of 6 SPDs installed which are spread into the sending and the receiving end which belongs to Class I, II, and III. The power line length of 1m, 50m, and 100m are applied to the 8 combinations of SPDs. The data transmission rate measurements are carried out 10 times for 30 seconds each with a network performance measuring program based on PC.

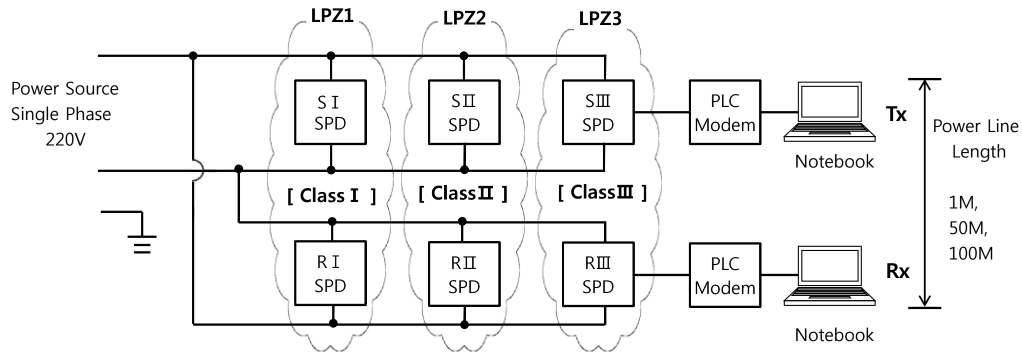

Figure 3. Test system model for performance measurements

The SPDs installed in our experimental system shows high impedance in the frequency region where the electric power is transmitted in the steady state. However in the frequency band where the information data is transmitted the impedance of the corresponding device shows very low value. This characteristic is also discussed in the next section with the experimental results. Therefore the communication system utilizing higher band for the higher data rate might be affected in the throughput performance. The current power line communication system uses the frequency band of 2MHz~50MHz to support the data rate of a few Mbps to hundreds of Mbps. In this frequency band the gain attenuation may be quite big depending on the device applied [10]. The performance degradation caused by this attenuation in high frequency band could be recovered with advanced modulation and channel coding techniques up to a certain level. However, the system might be blocked when the attenuation level exceeds the error control capability. More detailed discussion is continued in the next section with the measurement results.

3. Experiment Results

Experiment results are summarized in Table 1 and Figure 4 which show the performance of power line communication in terms of the data transmission rate for the various combinations of the SPD grade and the line length. Especially in Table 1, the data rate variation in percentile scale is also listed for quantitative comparisons. Eight representative combinations are shown for three different lengths. In case of power line length of 1m with all of the SPDs of Class I, II, and III applied both to the sending and the receiving end, there are about 50% loss of data transmission rate compared with the state of no application of SPD.

In cases of power line length of 50m and 100m, the effect of SPD grade is more sensitive. For example in 100m case, the power line communication is blocked when Class III is present regardless of the location in the network [11]. This phenomenon occurs in the 50m case in the similar manner. Overall results show that performances are more sensitive to the higher grade (especially when Class III is included in the combination) and longer line length.

Table 1. Results of Data Transmission Rate for various SPD Combination and Power Line

Application of SPDs	Data Transmission Rate [Mbps] by Power Line Length [meter]			Variation (%)		
	1m	50m	100m	1m	50m	100m
NONE*⓪	5.72	5.69	5.66	▼ 0.00	▼ 0.50	▼ 1.10
Sending End I ①	5.71	5.68	5.71	▼ 0.20	▼ 0.70	▼ 0.20
Sending End II ②	5.71	5.71	5.66	▼ 0.20	▼ 0.20	▼ 1.10
Sending End III ③	5.51	4.85	0.00	▼ 3.70	▼ 15.20	▼ 100.0
Sending and Receiving Ends III ④	3.11	0.00	0.00	▼ 45.60	▼ 100.0	▼ 100.0
Sending and Receiving Ends I + III ⑤	3.42	1.99	0.00	▼ 40.20	▼ 65.20	▼ 100.0
Sending and Receiving Ends II + III ⑥	0.00	0.00	0.00	▼ 100.0	▼ 100.0	▼ 100.0
Sending and Receiving Ends I + II + III ⑦	2.89	0.00	0.00	▼ 49.50	▼ 100.0	▼ 100.0

In Figure 5 through Figure 8 amplitude spectrums of the data transmission channel are shown for the cases where the degradation rate is over 40% compared with the no SPD channel assuming the channel length is 1m. The measurements are carried out with spectrum analyzer capable of sweeping 0.01MHz to 50MHz which are commonly used for broadband power line communication systems. According to the results the channel of 1m with no SPDs installed shows maximum of -23.6dB loss over the maximum gain level (0dB assumed) which is drawn as solid line in Figure 5. The maximum degradation is increased with the application of SPD in case 3 which is -63.5dB at 15.1MHz. The frequency band representing over -40dB of degradation is observed to be 13.8 ~ 17MHz. Here locations of SPDs are assumed to be both at sender (transmitter) and at receiver end.

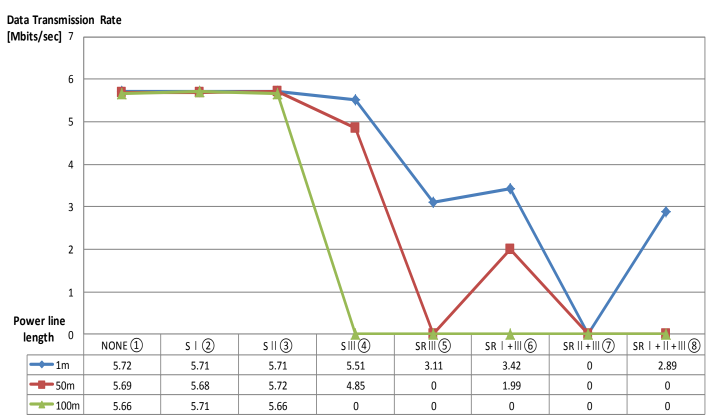

Figure 4. Comparison of data rate for combinations of SPD grade and line length

In the case 5 the SPD of Class I and III are installed at both the sender and the receiver side. In this case the maximum degradation is further increased into -79.7dB at the frequency of 13.9MHz as shown in Figure 6. The frequency bandwidth below -40dB is 11.3 ~ 16.6MHz which is almost the same as the case 4 mentioned above. The corresponding data rate degradation is about 40% which is around the same rate as the case 4 (45.6% degradation). In the case 6 the SPDs of Class II and III are installed at both ends. In this case the transmission is blocked for some reason. A maximum of -60dB was observed at 14.5MHz and the band below -40dB ranges from 11.4 to 18.2MHz as shown in Figure 7.

The result of the case 7 is shown in Figure 8 where the SPDs of all the classes (I, II and III) are applied. In this case the maximum loss of -83.9dB is monitored at the frequency of 14.5MHz. The range below -40dB loss is observed between 11.1 and 17.9MHz as shown in Figure 7.

From the observations on the data rate loss and the channel gain attenuation it can be conjectured that the Class III device plays an important role in the performance of the power line communication system. The data rate performance begins to degrade when the Class III device is first adopted in the sender (case 3). The degradation rate gets worse when the same devices are installed at both sides (case 4). The effect of the device of the other classes (1 and 2) seems less sensitive than Class III (case 1 and 2) although some worse combinations of different classes cause extreme performance as shown in case 6.

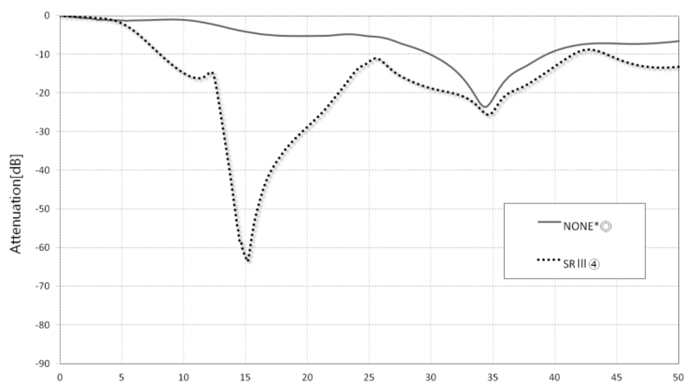

Figure 5. Channel spectrum for case 4

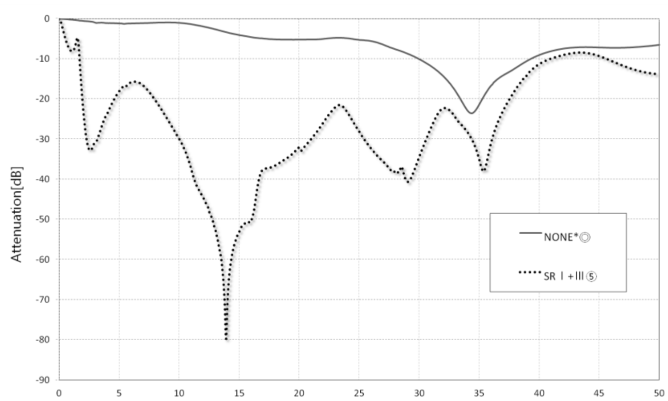

Figure 6. Channel spectrum for case 5

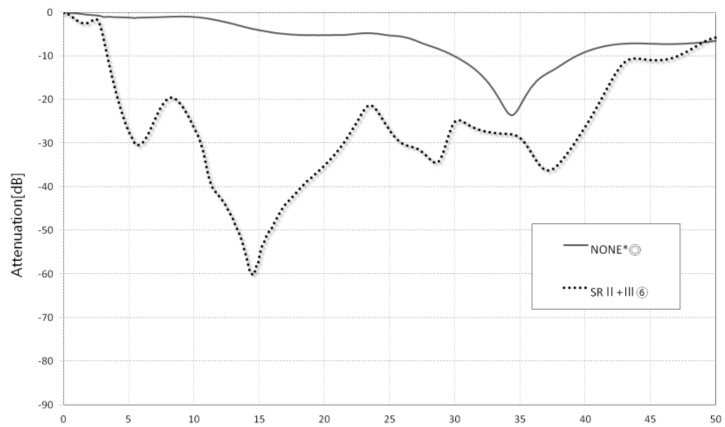

Figure 7. Channel spectrum for case 6

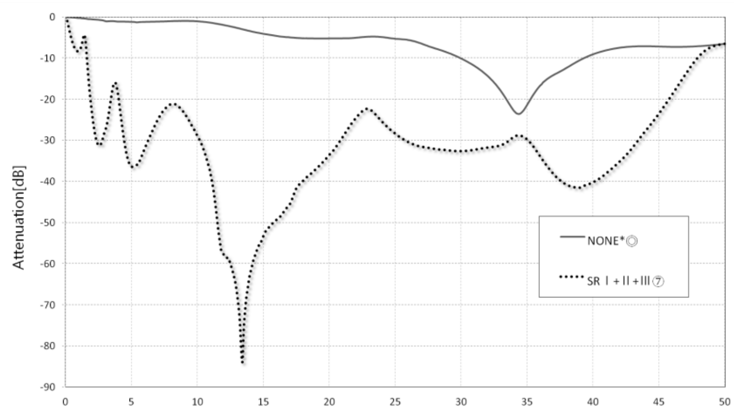

Figure 8. Channel spectrum for case 7

5. Conclusion

In this paper effects of the SPDs with ZnO varistor are discussed on the channel characteristics of the medium voltage transmission lines. In the experiment it is assumed that the power line communication system is being operated in the same power transmission lines where the SPDs are inevitably installed to protect the electrical appliances including the communication modules. In the laboratory experiments various combinations of the SPD classes and the channel length are tested to measure the effect of the SPD on the performance of the PLC network. Numerical results show that Class III SPD affects in larger scale than the other classes which gets worse in longer transmission lines. Especially with 100m line length the communication is blocked when Class III device is installed regardless of the location or the parameter combinations. This requires other appropriate alternative way to improve the performance of the communication system while maintaining the surge protection function. From the channel spectrum measurement is can be shown that the degradation in performance is closed related to the change of the load impedance due to the addition of the SPD. As the smart grid technology is spread over wider area of the transmission line the requirement levels for the stability and the rate of the data transmission system is expected to be higher. At the same time the request for installation of more SPDs is also expected to be increased to protect the various types of intelligent appliances from the lightning and the transient surges. Further researches are required to maintain the performance of the communication systems as well as the SPDs in the same power line networks

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