A new transmission system using the Protective Earth conductor for Narrow-Band PLC

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Abstract: One of the serious problems in the conventional transmission system, which uses the Neutral and Live (N-L) conductors, for the Narrow-Band Power-Line Communications (NB-PLC) is the low Signal to Noise Ratio (SNR) property. To improve it, a new signal transmission system, which uses the Protective Earth (N-PE) conductor instead of L, has been proposed in this letter. The proposed method is called N-PE system. The results show that the receiving SNR, the channel capacity, and the Packet Reception success Rate (PRR) values of the N-PE system were superior to those of the N-L system, except for the noise property.

Keywords: Power-Line Communication, Narrow-Band PLC, Neutral and Protective-Earth (N-PE) conductors, smart meter, differential-mode, common-mode

Classification: Transmission Systems and Transmission Equipment for Communications

References

1 Introduction

Two frequency bands for Power-Line Communication (PLC) systems are allowed in Japan. One is from 2 MHz to 30 MHz, which is called Broadband (BB) PLC and suitable for indoor high-speed communication (up to 200 Mbps). However, outdoor usage is not permitted because of the unintentional radiation problem [1, 2]. Another is the band from 10 kHz to 450 kHz, which is called Narrow-Band (NB) PLC and has been used to monitor and control the home appliances. Since the NB-PLC is permitted to use both for indoor and outdoor communications, it is expected as a method to realize new applications such as Automatic Meter Reading (AMR), Advanced Metering Infrastructure (AMI), and smart meters [3].

The conventional indoor PLC systems have injected and received the signals between the Neutral and Live (N-L) conductors, which are also called the differential-mode transmission. The appliances connected to the same conductors not only attenuated the propagating PLC signals but also injected noises, hence the Signal-to-Noise Ratio (SNR) characteristic was degraded. The SNR degradation was solved by a common-mode transmission system that was proposed by the authors, which injected and received the signals between all conductors and the earth [4]. The common-mode system worked effectively for the BB-PLC, because the common-mode impedance of the appliances was usually high at the band. Moreover, a kind of mode diversity could be employed to increase the channel capacity, since the common-mode is orthogonal to the differential-mode. However, the common-mode system could not be applied to the lower frequency band of NB-PLC systems, because the common-mode current flowing to the earth was detected as the earth leakage current so that the malfunction of the circuit breaker had occurred.

To avoid the malfunction of the Earth Leakage Circuit Breaker (ELCB), a new transmission system which injects and receives the PLC signals between Neutral and Protective Earth (N-PE) conductors is proposed in this letter. Note that a similar transmission system has been studied recently for the BB-PLC, which is called “Multiple-Input and Multiple-Output” (MIMO).
PLC and uses three injection/reception pairs of L-N, N-PE and PE-L to increase the channel capacity [5], since the PLC signals of MHz-band do not introduce the malfunction of ELCB. However, the feasibility studies of the application to the NB-PLC systems have not reported as far as the authors know.

2 Proposing system

The Low Voltage (LV) distribution system in Japan is a single-phase three-wire system as shown in Fig. 1. The conventional differential-mode PLC system has used two conductors L (Live₁ or Live₂) and N. Therefore, the signal has been disturbed by the appliances connected to the same conductors. On the other hand, the proposing system uses N and PE conductors. Since the appliances are not included in the signal circuit constructed by the sender and receiver modems as shown in the figure, the disturbance can be avoided.

Although another possible system was a Live and PE (L-PE) one to avoid the disturbance, it could not be adopted in our proposal. Since the mains voltage between L and PE conductors was dozens of times higher than that between N and PE conductors, the maximum noise voltage added to the mains one was also higher. Then the malfunction of the ELCB was easily introduced for the L-PE system. This is the same reason why the common-mode and MIMO system could not be applied to the NB-PLC system. In fact, the malfunction has not occurred in our laboratory, as far as the proposing system was carried out.

The evaluated PLC modem in this letter was MAX2990 Evaluation Kit by MAXIM, which is a candidate modem for the global standard of IEEE P1901.2 for the smart meter systems [6]. The used frequency band by this modem was from 130 kHz to 450 kHz [7].

3 Channel properties

The channel properties were measured in the authors laboratory. There are three rooms separated by a hallway with twelve outlets. Therefore, the number of total pairs was 144. The total measurement time for the results was
approximately 6 hours. While these measurements, the states of appliances were not changed [8].

Figure 2 (a) and 2 (b) compare the impedance values between N and L conductors with those of N and PE conductors measured at the outlets. The measured values were shown in the Cumulative Distribution Function (CDF) style, where the worst value was denoted as “CDF = MIN”. The low impedance property at the NB-PLC band shown in Fig. 2 (a) was caused by the appliances connected to the same conductors. On the other hand, the impedance values of the proposing system were relatively higher as shown in Fig. 2 (b). These impedance properties affected the noise properties and transfer functions of both systems as shown in Fig. 2 (c) to Fig. 2 (f).

The CDFs of the measured noises at the twelve outlets are shown in Fig. 2 (c) and Fig. 2 (d). The Resolution Bandwidth (RBW) of the used
spectrum analyzer was set to 3 kHz. Although the noise power less than −90 dBm could not be measured, it is shown that the amount of outlet noise within a frequency band from 100 kHz to 450 kHz of the N-PE system was larger than that of the N-L system.

The transfer functions of both transmission systems measured at the 144 pairs are shown in Fig. 2 (e) and Fig. 2 (f). The signal attenuation of N-L and N-PE systems at 400 kHz and CDF = 50%, for example, are 68 dB and 15 dB, respectively. The N-PE transmission system made major improvements in the propagation loss, because the large attenuation for the N-L system was introduced by the capacitors in EMC (Electro-Magnetic Compatibility) filters embedded in appliances connected to the same N-L conductors. The impedance of the capacitors at the NB-PLC frequency band was very low. On the other hand, the proposing system was affected not by the appliances but only the attenuation caused by power-line cables, so that Fig. 2 (f) showed a downward tendency at the band.

The receiving $SNR_n$ [dB] was derived from the transfer function $TF_n$ [dB] of Fig. 2 (e), Fig. 2 (f) and the noise power $N_n$ [dBm/RBW] of Fig. 2 (c), Fig. 2 (d) at CDF = 50%. The result is shown in Fig. 2 (g) obtained by the following equation.

$$SNR_n = \frac{S_n + TF_n}{N_n}$$

where $S_n$ [dBm/RBW] is the transmitting signal power of PLC modem at the frequency point $n$. The point $n (= 1, 2, 3, \ldots, M)$ is equivalent to the frequency $f$ (130 kHz $\leq f \leq$ 450 kHz), where $M = 314$ in this letter. Since the transfer function of the N-PE system was superior to that of the N-L system, the SNR value was also better. For example, the SNR values at 400 kHz of the N-PE and the N-L systems were 32 dB and −2 dB, respectively.

The channel capacity $C_n$ values given by Shannon-Hartley theorem using the derived $SNR_n$ values could be calculated by Eq. (2). Then the total channel capacity $C$ of the whole frequency band was given by Eq. (3).

$$\frac{C_n}{RBW} = \log_2(1 + r_n)$$

$$C = \sum_{n=1}^{M-1} \frac{C_n}{RBW}(f_{n+1} - f_n)$$

where $r_n \equiv 10^{SNR_n/10}$. The obtained capacity $C$ of the N-PE system and the N-L system are 2.55 Mbps and 168 kbps, respectively. Therefore, it could be concluded that the capacity of the N-PE system was improved 15 times more than that of the N-L system in average.

4 Evaluation of proposed system by PLC modems

The performance of the proposed system was evaluated with an index of Packet Reception success Rate (PRR) by the modem MAX2990. The PRR value was the ratio when 1000 packets were sent and their packet size was 7 Bytes [8, 9]. The PRR correlation diagram between both systems is shown
in Fig. 3. All the points are plotted on or below the diagonal, that is the PRR performance of all 144 pairs using the N-PE system was better than or equal to that of the N-L system. The 122 outlet pairs were plotted on the vertical line of PRR = 1 of the N-PE system, and 48 pairs were plotted on the horizontal axis of PRR = 0 of the N-L system. Therefore, the PRR performance of N-PE transmission system is overwhelmingly superior to that of the N-L transmission system. These results agreed well with the channel properties discussed in Sec.3.

5 Conclusion

It was shown that the proposed transmission system using the N-PE conductors was so effective to improve the signal propagation loss property, so that the SNR characteristic was also improved comparing to the conventional system using the N-L conductors while the noise property of the proposed system was inferior to the conventional one. The receiving SNR value at 400 kHz, for example, of the N-PE system was 34 dB superior to that of the N-L system, so that its channel capacity was improved 15 times more than that of the N-L system according to our scenario. It was also shown that the PRR performance of the N-PE system was always superior to that of the N-L system in our laboratory outlets when MAX2990 was used as the NB-PLC modem.

Although the details could not be explained in this letter, other power-line environments of buildings and houses have shown the same results according to our preliminarily measurements. These results of the field measurement campaign will be summarized in the near future. The consideration how to cooperate with outlets which do not have the PE conductor is another future work.

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