CONSEIL INTERNATIONAL DES GRANDS RÉSEAUX ÉLECTRIQUES
INTERNATIONAL COUNCIL ON LARGE ELECTRIC SYSTEMS

http:d2cigre.org
http://cigregroups.org/display/SCD2

STUDY COMMITTEE D2
INFORMATION SYSTEMS AND TELECOMMUNICATION

2017 Colloquium
September 20th to 22nd 2017
Moscow – RUSSIA

Development and Introduction of Communication Devices Corresponding to New Applications

Yusuke Hattori*, Hiroki Kono
Chubu Electric Power Co., Inc.
(JP)

Norio Sasaki
Tohoku Electric Power Co., Inc.
(JP)

Takeshi Oda, Tasuku Hanaumi
Tsuken Electric Ind. Co., Ltd.
(JP)

Tetsuya Seki
Nishimu Electronics Ind. Co., Ltd.
(JP)

SUMMARY

Japanese power companies, with environmental changes in the electricity business, have been conducting development and introduction of communication systems that correspond to the complexity and sophistication of the modern power system. This paper describes development cases of a transfer trip signal transmitter as a countermeasure for reverse power flow at distributing substations designed by the Chubu Electric Power Co., Inc. and a Digital Power Line Carrier (DPLC) system for use with power lines produced by the Tohoku Electric Power Co., Inc.

In recent years, distributed power sources utilizing renewable forms of energy such as solar photovoltaics have increased. The power flow from distributed power sources to those systems higher than the transformer of the transmission substation may cause some electric safety and quality problems. To solve this problem, we needed to transfer the trip signal of the transmission protection relay from the high-order transmission substations at the sending ends to the distribution substation where cubicle-type gas-insulated switchgears are installed. Chubu Electric Power Co., Inc. developed a transfer trip signal transmitter connected to the existing loop-type optical communication systems (LLN). In addition, through miniaturization and operational improvements, we can considerably reduce costs and construction times by decreasing the number of opposite devices and the need for optical fiber cables.

Conventionally, in mountainous areas where communication lines are difficult to deploy, a Power Line Carrier system using high-voltage (66kV–154kV) power lines provides communication channels. However, along with the rapidly increasing popularity of IP technology and the digitization of communications devices, development of a Digital Power Line Carrier (DPLC) system is strongly desired. The Tohoku Electric Power Co., Inc. developed a novel DPLC system for use with power lines. It is applicable to transmission lines with congested channel arrangements, and for use even in the presence of severely delayed paths. The DPLC system employs such technologies as adaptive equalizer, digital AFC system, and narrow bandwidth transmission scheme. A verification test on a transmission line with the severe frequency-selective channel confirmed that the DPLC system has totally satisfied performance criteria.

KEYWORDS

Reverse power flow, Transmission substation, transfer trip signal, Power line, Digital transmission, Adaptive equalizer, Carrier frequency offset

* 1 Higashi-shincho, Higashi-ku, Nagoya, Aichi 461-8680, Japan
Fax: +81-52-957-1351 e-mail: Hattori.Yuusuke@chuden.co.jp

2.2 Development of DPLC System by Tohoku Electric Power Company

2.2.1 Background and motivation

A power line carrier system that uses high-voltage transmission lines has a long history as a communication technique for the stable operation of power systems. A power line carrier system not only has high reliability in cases of a disaster, it can also be deployed at electric stations in mountainous areas where metal cables are difficult to deploy, as illustrated in Figure 5. Along with a rapid progress of IP technology and digital communication devices, development of a DPLC system is strongly demanded.

Tohoku Electric Power Company developed a DPLC system having bandwidths of 24 kHz and 48 kHz in the frequency band of 100-450 kHz. The transmission rate can be 103 kbps with a bandwidth of 24 kHz and 206 kbps with a bandwidth of 48 kHz. The authors developed a DPLC system using 64 Quadrature Amplitude Modulation (64QAM), adopting a Least Mean Square (LMS) linear adaptive equalization for scheme and a Carrier Frequency Offset (CFO) estimation and compensation scheme for application to the transmission line of a severe frequency-selective channel. Then we conducted a field experiment to verify its performance.

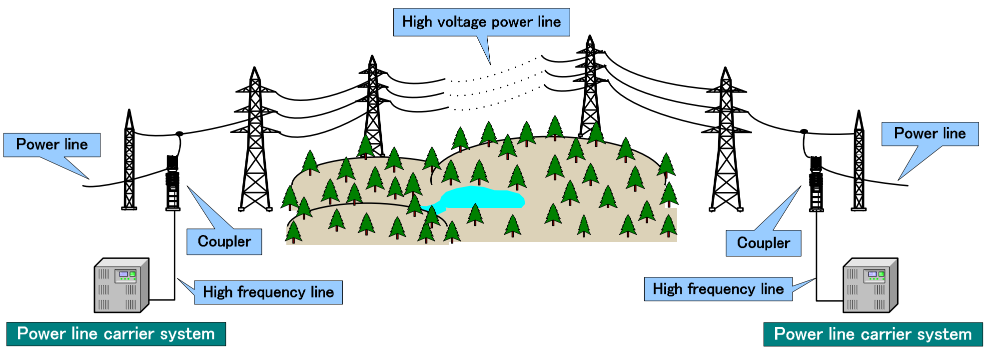


Figure 5: Overview of the power line carrier system.

2.2.2 Applied technology for DPLC

(1) Linear Adaptive equalizer using the LMS algorithm

Reflection of the transmitted signal from the power transmission line branch points and electric station terminators produces severely delayed signals. The presence of severely delayed signals produces inter-symbol interference and degrades the Bit Error Rate (BER) performance of the DPLC system. To improve the BER performance, a linear adaptive equalizer using the LMS algorithm was implemented in our developed DPLC system. The adaptive LMS equalizer implemented in the DPLC system is shown in Figure 6.

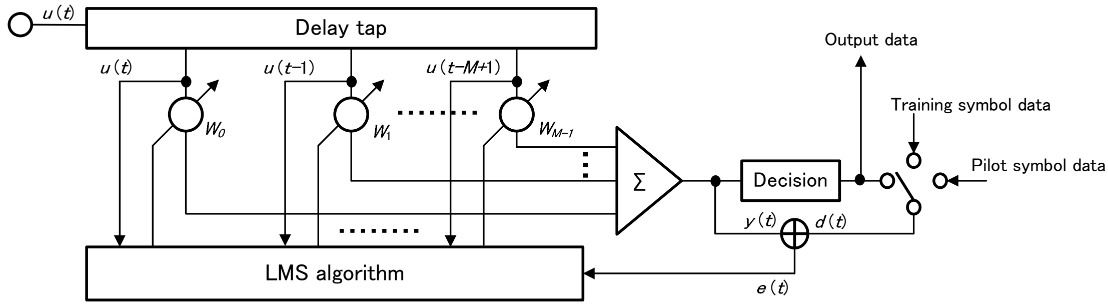


Figure 6: Adaptive LMS equalizer implemented in the system.

(2) CFO estimation scheme

The presence of CFO between of the local crystal oscillators in the transmitter and receiver degrades the BER performance after equalization. The authors developed a Digital Auto Frequency Control (DAFC), which can perform accurate CFO estimation and compensation even for severely delayed signals. The CFO estimation and convention system is depicted in Figure 7. Autocorrelation measurement for CFO estimation uses a 4PSK training sequence, with received signal $r(t)$ at time t and an N symbol delay received signal $r(t\text{-}N)$.

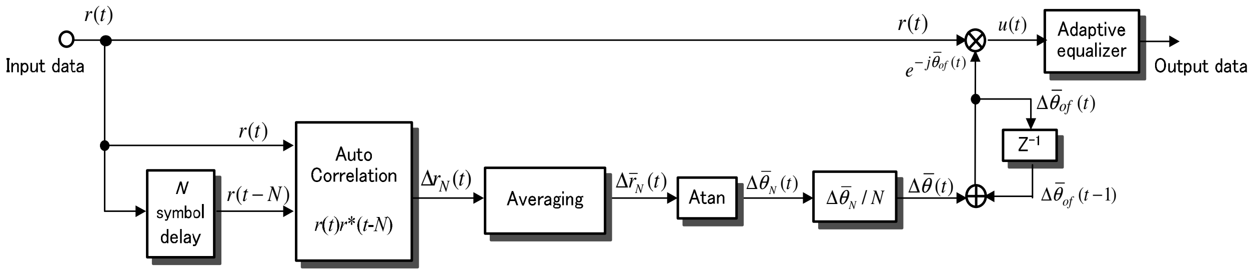
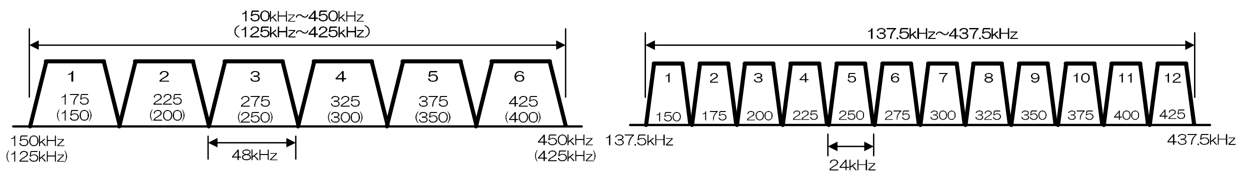


Figure 7: Block diagram CFO estimation and compensation system.

(3) Narrow bandwidth scheme

In this section, we describe carrier frequency deployment and the frequency bandwidth. To allow deployment of multiple channels of a transmission line, a narrow band transmission scheme of bandwidth 24 kHz (103 kbps) is applied in addition to the scheme for 48 kHz (206 kbps) transmission bandwidth.

As portrayed in Figure 8 (a) and (b), the bandwidth 48 kHz scheme can be deployed with 6 channels in the 125 to 450 kHz frequency band, with a carrier frequency interval of 50 kHz (175 kHz, 225 kHz, …, 425 kHz or 150 kHz, 200 kHz, …, 400 kHz). The 24 kHz bandwidth scheme can be deployed 12 channels in the frequency band for 137.5 to 437.5 kHz, with a carrier frequency interval of 25 kHz (150 kHz, 175 kHz, …, 425 kHz). These frequency bandwidths are achieved using a Nyquist filter with a roll-off factor of 0.4.



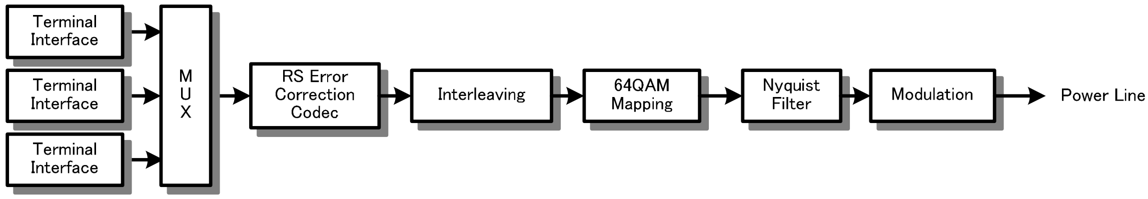
(a) Frequency bandwidth: 48 kHz (b) Frequency bandwidth: 24 kHz

Figure 8: Carrier frequency deployment with 48 kHz and 24 kHz frequency bandwidths.

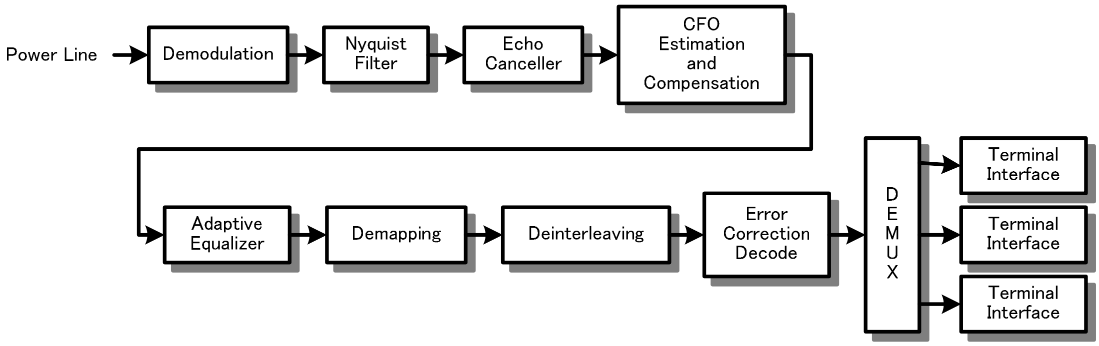
2.2.3 Equipment specification of developed DPLC

In this section, we describe a block diagram of the developed DPLC and its specification. First, the transmission system is presented in Figure 9 (a). The multiplexing device multiplexes on a terminal apparatus data. The multiplexed data are error-correction coded using a Reed-Solomon code RS(255, 239). The encoded data are first interleaved and then mapped to 64 QAM symbol points. Bandwidth limitation is by a Nyquist filter with a roll-off rate of 0.4; it is sent to the power transmission line.

The receiving system is presented in Figure 9 (b). The signal demodulated by the demodulator is bandwidth-limited by the Nyquist filter. At the echo cancellation section, to use the identical frequency band to that of the transmission signal and the received signal, the transmission signal included in the received signal is cancelled. The CFO estimation and compensation section compensates the amount of phase rotation included in the reception signal. The adaptive equalizer corrects the intersymbol interference occurring in the received signal because of delayed paths. The error correction section decodes the code and corrects



(a) Transmission System



(b) Receiving System

Figure 9: Block diagram of developed DPLC.

Table 1: Specifications of the developed DPLC

TX powre	20 dBm or 26 dBm
Modulation	64QAM (Symbol Rate = 34.3 kbps , Bandwith = 48 kHz) (Symbol Rate = 17.2 kbps , Bandwith = 24 kHz)
Filter	Root Nyquist Filter (Roll-off Facter = 0.4)
Adaptive Equalizer	Transversal Filter (Tap M = 24) LMS Algorithm
Echo Canceller	Transversal Filter (Tap M = 160) LMS Algorithm
Error Correction	Reed-Solomon Code RS(255,239)
Interleaving	Symbol-Interleave (256 byte × 3 byte)
Bit Rate	205.8 kbps(48 kHz), 102.9 kbps(24 kHz)
Maximum CFO	±15 ppm
Carrier Terminal Interface	Ethernet channel Digital channel (64 kbps) Audio channel

Figure 10: Appearance of developed DPLC

the bit error generated in the transmission channel. The demultiplexer separates the data for the terminal. The developed DPLC has the specifications presented in Table 1 and the appearance portrayed in Figure 10.

2.2.4 Field experiment results

(1) Field experiment setup using DPLC system

The field experiment setup using the developed DPLC system is presented in Figure 11. The DPLC system is a communication system using a frequency band of 100-450 kHz. Here, LT is connected to a power transmission line to prevent high frequency inflow to a power station and substations. The DPLC system is connected to the power transmission line through CC and CF. The branching of the power transmission line used in the field experiment has not used a line trap. Therefore, reflection from the branching point causes a delayed paths with large amplitude value. Furthermore, the noise encountered in the transmission line is characterized by superposition of the impulse noise and Gaussian noise.

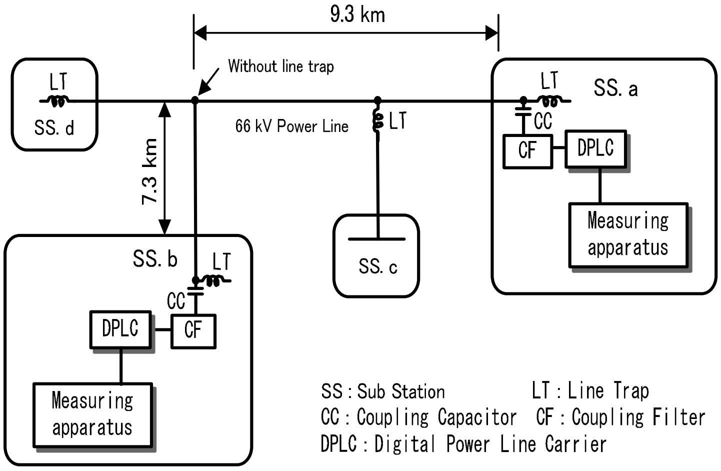


Figure 11 : Field experiment setup using developed DPLC system.

(2) Transmission channel performance

First, the channel frequency response measured in the field experiment is portrayed in Figure 12. Measurements were taken over a frequency range of 400- 450 kHz with transmission power of 0 dBm. Results show that the channel frequency response fluctuates because of the presence of multiple delayed paths in the transmission line. The power delay profile measured using the 4PSK training sequence is presented in Figure 13. It can be confirmed that the delayed path is a l

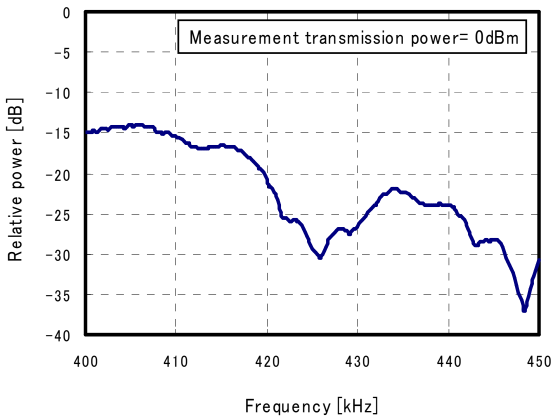


Figure 12: Frequency characteristics of the real field.

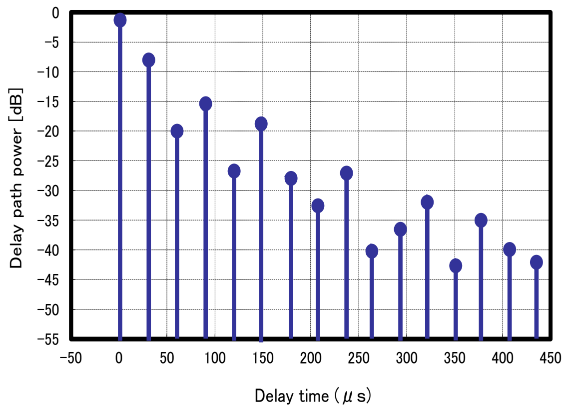


Figure 13: Frequency characteristics of the real field.

long delay transmission line presence up to 438 μs (131.4 km) and that it has numerous delayed paths. The interval of discrete propagation paths presented in Figure 13 is identical as the symbol-spaced (29.2 μs) of 4PSK. The power-valued path gain of L discrete symbol-spaced propagation paths are given as $\{(|h(0)|^2, |h(1)|^2, . . . , |h(L\text{-}1)|^2)$. Furthermore the power path gain with $\left[\sum_{i=0}^{L-1} |h(i)|^2\right] = 1$, where $h(i)$ denotes the respectively complex-valued path gains of the i-th path.

(3) MSE convergence performance

The Mean Square Error (MSE) convergence performance obtained by averaging the results of 10 trials as shown in Figure 14. A 4PSK training sequence with 3520 symbols was used. It can be seen that the tap weight vector is converged after about 2500 times updating. The average MSE after convergence is -31.8 dB (averaging for 3000-3520 iterations).

Average MSE was observed as about -31.8 dB, which is higher than the theoretically predicted value (The theoretical MSE in case given thermal noise power of -40.0 dBm is -34.9 dBm). This degraded MSE might be due to sampling timing error at the receiver and the echo cancel error. However, in this case, the value can compensate for bit error rate 1×10^{-7} or lower with 64 QAM, even in the presence of severely delayed propagation paths.

(4) CFO estimation performance

CFO was set to 30 ppm for the experiment. The average CFO estimation error characteristic in 10 trials is presented in Figure 15. 4PSK training sequence was used. It is apparent that the CFO estimation error becomes within 0.2 ppm (0.085 Hz) in absolute value (which is necessary for CFO compensation), even in the presence of severely delayed propagation paths, if a 4PSK training sequence of approximately 1200 symbols is used. If the training sequence of length of longer than approximately 1400 symbols is used, then the CFO estimation error can be within 0.1 ppm (0.043 Hz).

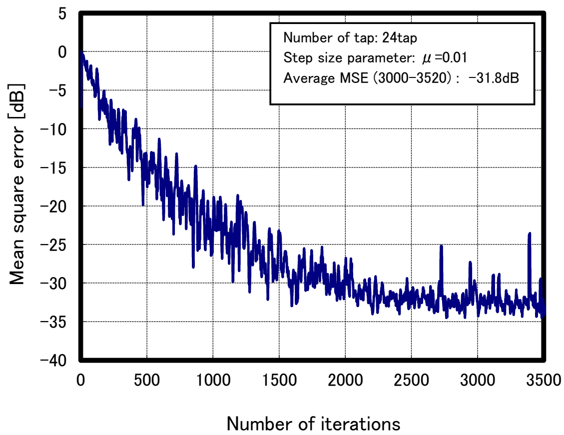


Figure 14: MSE convergence performance.

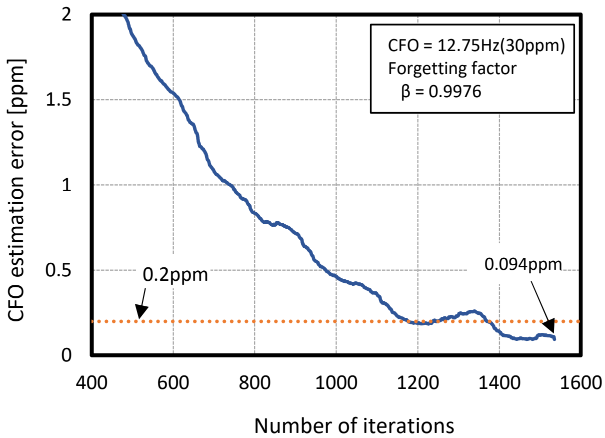


Figure 15: CFO estimation performance.

(5) BER measurement

BER measurements were taken during 25-days period using our developed DPLC with the parameters presented in Table 2. In this case, the DPLC transmission distance was 16.6 km. CFO was 30 ppm. The received SNR was 40 dB. The measurement bit error rate was obtained using 64 kbps digital channel interface.

It was confirmed that bit error rate 6.2×10^{-7} transmission was achieved. In this case, results showed better performance than the required BER performance (1×10^{-6}). The developed DPLC is useful in the presence of severely delayed propagation paths.

Table 2 Results of BER measurement.

Measurement bit rate	Number of transmission bits	Number of error bits	Bit error rate
64 kbps	1.3603×10^{11}	83681	6.15×10^{-7}

3. Future prospects

We need to continue working on the new challenges associated with the environmental changes surrounding the electricity business and the development and standardization of communication technology. We are committed to providing low-cost communication networks, while flexibly addressing the needs of a wide variety of communication lines.