Simulation and Experimental Study of Low Voltage Power Line Carrier Communication

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Abstract. This paper presents the simulation and experimental research of low-voltage power line carrier communication. The choice of communication method is an important factor in determining the communication quality of the communication system. For the communication mode of low-voltage power line as carrier, this paper prefers the direct sequence spread spectrum communication system as the communication method. In this paper, the simulation function is realized by establishing various parts of the system simulation model. The simulation reflects the stability of the direct sequence spread spectrum communication system and has strong anti-interference ability. In this paper, the spread spectrum communication method is used to simulate low-voltage power line communication in the laboratory environment, and good results are also obtained. The direct sequence spread spectrum communication system is a better choice for low voltage power line carrier communication.

1. Introduction
With the continuous development of the national economy, the application of transmission cables and distribution cables has gradually increased, with a wide distribution and high value. In the current information age, real-time communication is a very important part of the power system. With the continuous development of modem technology and microelectronic technology, power line carrier communication has become possible. The application of power line communication benefits to reducing the additional erection of communication base station, realize the networking function and automatically detect the current grid environment. Therefore, achieving low-voltage power line carrier communication is a very advantageous communication method. This paper studies the simulation of communication methods for low-voltage power lines as carriers.

2. Analysis of the Way of Low Voltage Power Line Carrier Communication
Compared with analog communication, digital communication has good confidentiality and strong anti-interference ability, which is suitable for computer communication needs. Moreover, only the digital communication mode is adapted to the spread spectrum method in which digital coding is used as a spreading code. Therefore, the communication method selected in this paper is the spread spectrum communication. It is a transmission mode in which the bandwidth occupied by the transmission signal exceeds the minimum bandwidth required to transmit the information. The expansion of the bandwidth is performed by the modulo-2 superposition (time domain multiplication) of the baseband digital signal to be transmitted by the spreading code, and is received. The terminal receives with the same codeword, including de-spreading and recovery of information data to achieve the purpose of suppressing interference.
2.1. Direct Sequence Spread Spectrum Communication System Simulation

The method of spreading the spectrum in this paper is the direct sequence spread spectrum operation mode, which directly uses the spread code sequence with high code rate to spread the spectrum of the signal at the transmitting end, and de-spreading with the same spreading code sequence at the receiving end to restore the original information. Figures 1 and 2 are block diagram and a simulation model diagram of a direct sequence spread spectrum communication system.

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**Figure 1.** Direct sequence spread spectrum communication system block diagram.

**Figure 2.** Direct sequence spread spectrum communication system simulation model diagram.

The transmitting end performs LDPC channel coding, direct sequence spread spectrum modulation, BPSK modulation on the original data signal from the source, and then sends the signal into the channel. The signal adds Gaussian white noise and narrowband single frequency interference in the channel. After receiving the signal, the receiving end first sends the signal to the interference suppression module. Then the interference suppression module performs synchronization (PN code acquisition and PN code tracking), completes de-spreading after synchronization, demodulates to obtain baseband data, and finally decodes through LDPC, restore the original sequence of information sent. The whole system has a channel and modulation module, an interference suppression module, a synchronization and de-spreading module, and a carrier synchronization module.
The channel and modulation module performs BPSK modulation on the original information sequence, and is coupled with the sinusoidal carrier after the PN code spread spectrum communication, and interferes with the output signal through the Gaussian noise channel; the interference suppression module performs filtering and noise reduction processing on the signal through the channel; synchronization and dispreading module synchronizes the PN code so that the transmitting and receiving parties are aligned in time, and then filters the PN code superimposed on the signal; the carrier synchronization module extracts the modulated carrier in the same phase and frequency, and finally outputs the signal of direct sequence spread spectrum communication system.

2.1.1. Channel and modulation module. In order to reduce the error, the simulation is used the encoded signal as the signal from the source. The LDPC-encoded signal is coupled with the spread-spectrum PN code. After BPSK modulation, the analog noise is applied through the Gaussian noise channel and output to the next stage via the sinusoidal carrier.

Spread spectrum modulation is implemented by multiplying a signal to be spread and a spreading code in the time domain. The spreading code uses an m-sequence PN code, that is, a pseudo-random sequence of a maximum-length linear shift register sequence. The narrowband signal is transmitted after being spread, and once there is interference in the transmission process, the de-spreading is equivalent to spreading, which greatly reduces the spectral density of the interference signal, thereby achieving the purpose of anti-interference. Figure 3 and Figure 4 show the before and after spread spectrum comparison.

![Figure 3. Un-spreading spectrum spectrogram.](image1) ![Figure 4. Spreading spectrum spectrogram.](image2)

The spreading code is a kind of pseudo-random code. In theory, it is ideal to use a pure random number sequence to spread the spectrum of the signal. However, because of its non-reproducibility, the pseudo-random code is used to de-spread at the receiving end and then restoration the signal. According to the Shannon theory, for a continuous channel interfered by additive white Gaussian noise, the channel bandwidth is B, the signal-to-noise ratio is S/N, and the channel capacity formula is shown in equation (1),

\[ C = B \log_2 \left(1 + \frac{S}{N}\right) \]

That is, in a given channel, if the signal-to-noise ratio is small, the bandwidth can be extended to maintain the transmission capacity. This is a measure of using bandwidth for power. Spread spectrum communication is to spread the spectrum of the original signal by 10-100 times and then transmit it, thereby improving the anti-interference ability of the communication.

2.1.2. Interference suppression module. The simulation uses the transform domain interference suppression algorithm to suppress the influence of the interference superimposed on the signal of the system, so that the interference is effectively suppressed within the interference tolerance of the system, and its principle is shown in Figure 5.
Figure 5. Transform domain interference suppression technology block diagram.

The simulation uses FFT overlap transform interference suppression algorithm. When the narrowband interference is equivalent to the spread spectrum signal energy concentrated in a very narrow frequency band, it appears as a narrow peak in the frequency domain, so the mixed signal can be first transformed into the frequency domain to detect the spectral position of the interference, and these spectra are removed or attenuated, and finally the inverse transform is reduced to a time domain signal for de-spreading. The mathematical model is shown in Figure 6, where $W$ is a window function, $\text{abs}$ and $\text{angle}$ are the amplitude and phase after solving the Fourier transform, $\text{Thre}$ function determines the threshold value of the spectral line, and $P$ function is the spectral line operation function.

Figure 6. FFT overlap transform interference suppression mathematical model.

Adaptive to determine threshold, the threshold value is usually determined based on the current one or several FFT transformation values, as following equation (2).

\[
\text{Thre} = \text{Thre}_{\text{min}} + \eta \frac{1}{MN_{\text{FFT}}} \sum_{j=1}^{M} \sum_{m=1}^{N_{\text{FFT}}} \text{abs}(u_{j,m})
\]

(2)

Where, $\text{Thre}_{\text{min}}$ is the minimum threshold value, $M$ is the number of FFT transforms, is the length of the FFT transform, $N_{\text{FFT}}$ is the attenuation coefficient, and $\eta$ is the FFT transform value, $(u_{j,m})$ is the FFT transform value after the input signal $x$ is multiplied by the window function $W$, which is in equation (3)

\[
u_{m} = \sum_{n=1}^{N_{\text{FFT}}} x(n)w(n)e^{-j2\pi nm/N_{\text{FFT}}} m = 1, \cdots, N_{\text{FFT}}
\]

(3)

In the simulation, the time domain signal must be windowed before the FFT operation. Otherwise, the spectrum leakage of the interference signal will be caused and the entire signal frequency domain is polluted. The interference is not completely eliminated, or the bandwidth of the elimination is increased, and the damage to the useful signal is aggravated. The Chebyshev window with lower side lobes is used in the simulation.

2.1.3. Synchronization and de-spreading module. The key to the spread spectrum system of the PN code synchronization is divided into two stages: capture and tracking. This simulation adopts the parallel capture mode, the search time is short and the phase of the received pseudo code can be exhausted at one time. The received signal performs correlation operations simultaneously with all possible pseudo code phases in different paths, and compares all the operation branches and correlation values, and the pseudo code phase of the branch with the largest correlation value is determined as the initial phase of the received pseudo code. The parallel filter is the capture unit used in the simulation. The simulation uses the delay lag phase-locked loop to achieve the purpose of
tracking, detects the phase difference between the sequences, and uses the signal reflecting the phase error to adjust the phase of the local sequence to achieve the purpose of tracking. This simulation also uses Doppler shift estimation and its compensation technique. The principle is that the assumption is shown in equation (4).

\[ s_i = PN(t) \cos\left( \left( \alpha_i + \alpha_j \right) t + \phi_i \right) \]  

(4)

The local reference signal is shown in equation (5) and equation (6).

\[ I_{\text{reference}} = PN(t) \cos(\omega_d t) \]  

(5)

\[ Q_{\text{reference}} = PN(t) \sin(\omega_d t) \]  

(6)

The FFT output in node N is shown in equation (7).

\[
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi m}{N} \right) \right| \\
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi k}{N} \right) \right| \\
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi m}{N} \right) \right| \\
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi k}{N} \right) \right| \\
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi m}{N} \right) \right| \\
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi k}{N} \right) \right| \\
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi m}{N} \right) \right| \\
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi k}{N} \right) \right| \\
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi m}{N} \right) \right| \\
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi k}{N} \right) \right| \\
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi m}{N} \right) \right| \\
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi k}{N} \right) \right| \\
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi m}{N} \right) \right| \\
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi k}{N} \right) \right| \\
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi m}{N} \right) \right| \\
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi k}{N} \right) \right| \\
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi m}{N} \right) \right| \\
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi k}{N} \right) \right| \\
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi m}{N} \right) \right| \\
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi k}{N} \right) \right| \\
|P(k)| = \frac{1}{M} \left| \sin\left( \frac{\omega_d M}{m} \right) \sin\left( \frac{\omega_d M - \pi m}{N} \right) \right| \\

In the formula, \( \omega_d = \pi f_T, k = 0,1,2,\ldots,N-1; M \) is the length of the PN code. When \( \omega_d M - \frac{\pi m}{N} k \), \( |P(k)| \) takes the maximum. Set a threshold to compare the k FFT output values. If the threshold is exceeded, the pseudo code is synchronized.

### 2.1.4 Carrier synchronization module

Carrier synchronization means that in coherent demodulation, the receiving end provides a coherent carrier that is in phase with the modulated wave in the received signal. The acquisition of this carrier is called carrier extraction or carrier synchronization. The simulation uses a self-synchronization method to extract directly from the received modulated signal. The received signal in the simulation contains the carrier component, so the narrow-band filter is used to directly extract the signal using the phase-locked loop. This simulation uses the Costas loop for carrier synchronization. The principle is as shown in Figure 7.

![Costas Ring carrier synchronization block diagram](image)

Figure 7. Costas Ring carrier synchronization block diagram.

### 2.2 Direct sequence spread spectrum communication system simulation results

A commonly used indicator in a communication system is the bit error rate, which is the ratio of the number of transmitted errors to the total number of codes transmitted. Figure 8 shows that the bit error rate is lower under larger samples. Figure 9 shows that the input signal above and output signal under. The comparison shows that simulation has achieved good results. Figure 10 is a demodulated constellation diagram. It can be seen that a set of points is displayed at -1 of the constellation diagram, indicating that the system established by simulation is stable. In the hardware circuit test experiment with simulation matching, from the waveform of Figure 11, the signal distortion is small, the waveform is intact and clear, which confirms the correctness of the simulation.
3. Conclusion
Aiming at the low-voltage power line carrier communication method, this paper proposes a direct-sequence spread spectrum communication system model, and carries out simulation and experimental tests. The simulation model adopts the observation mode of input and output contrast, and the output is almost undistorted, and the attenuation is extremely low. The error rate of the signal obtained by the simulation is also at a very low ratio, the communication quality is high, and the signal can be transmitted efficiently and correctly. In the actual experimental experiment in the laboratory environment, the obtained signal waveform is also clear and stable, and the correct square wave signal is output within a certain accuracy range. The simulation and experiment verify each other, which shows that the direct sequence spread spectrum communication system has strong anti-interference ability and good stability. Therefore, the direct sequence spread spectrum communication system can achieve better communication results.

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