Noise Reduction Method for Low Voltage Power Line Carrier Communication

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ABSTRACT. In order to improve the performance of electricity information collection system, this paper studies and proposes a new method of low-voltage power line carrier signal frequency domain noise reduction. It includes frequency domain decomposition of carrier signal, filtering noise reduction and signal frequency domain restoration. Then compared our method with the wavelet packet noise reduction method based on multi-resolution. The experimental results show that the proposed algorithm is better than the comparison algorithm under different modulation modes and carrier frequencies, especially suitable for carrier signal noise reduction under bad channel conditions. The algorithm proposed in this paper has good anti signal attenuation performance, and it can effectively enhance the SNR, and ensure the transmission performance and system reliability of the electricity information collection system.

1. Introduction

The power information acquisition system touches the user side at zero distance, and carries user's electricity consumption and fee control information. Its accurate transmission under complex operating conditions has an important role in the improvement of two-way interaction capability of smart grid [1]. Low Voltage Power Line Communication (LVPLC) technology as an effective data transmission mode to solve the "last mile" problem, has many advantages such as wide coverage, easy installation, and low cost [2]. It is the supporting communication technology of power information acquisition system.

However, compared with traditional communication medium, shared power line determines the information data transmission process is susceptible to multiple noise sources and time-varying strong noise in power line channel, seriously reduces the reliability of LVPLC. Therefore, it is necessary to study high-reliability signal modulation/demodulation methods to reduce the influence of power grid noise, which is of great significance to improve the interactive performance and reliability of power information [3-4].

The current mainstream noise processing solutions include spread spectrum communication technology, multi-carrier orthogonal frequency division multiplexing (OFDM) technology, and noise cancellation algorithms [5]. Spread spectrum communication technology reduce communication bit error rate at the expense of bandwidth. In the communication process using OFDM technology, it will still be affected by complex noise of the low-voltage power distribution network [6]. Therefore, the design of effective noise elimination algorithm is particularly important to realize reliable communication of power line carrier. In order to solve this problem, this paper classifies and models the noise characteristics of LVPLC power line channel in the power information acquisition system, analyzes and studies the carrier modulation method, converts the carrier signal noise reduction into the signal frequency domain separation problem, and proposes a new noise reduction method for carrier
signal in frequency domain. Experiments show that the proposed method can effectively reduce noise of low-voltage power line carrier communication in different communication scenarios, and improve the SNR of system signal transmission.

2. Noise Analysis of LVPLC
Noise in low-voltage distribution network is an important factor affecting the quality of LVPLC. It has many characteristics such as wide range of noise sources and many types. At present, scholars divide low-voltage power line noise into five categories [7]: colored background noise, narrow-band noise, periodic impulse noise synchronous to the power frequency, periodic impulse noise asynchronous to the power frequency and random impulse noise.

Colored background noise is a type of noise with low power spectral density generated by electrical equipment represented by household appliances. It covers the entire communication frequency band and is one of the key parameters determine low-voltage power line communication quality and channel capacity [8]. At present, the autoregressive AR model is commonly used to estimate this type of noise, the transfer function of P-order AR model is:

$$H(z) = \frac{1}{A(z)} = \frac{1}{1 + \sum_{i=1}^{P} a_i Z^{-i}}$$

(1)

Where $P_i$ is the $i$-th power measured by the regional master meter, $P_{ave}$ is the average power detected by the regional master meter every day, and $n$ is the daily power detection times of the regional master meter.

In this formula, $A(z)$ is input function, $a_i$ is the parameter to be measured in channel.

Random impulse noise is mainly caused by instantaneous breaking; its mathematical model can be expressed as:

$$N_{noise} = \sum_{i=1}^{l} Ae^{-i/d} \sin[2\pi f(t - t_{ave}) + \phi]$$

(2)

In this formula, $l$ is the number of pulses; $A$ is pulse amplitude, ranging from 0.4 to 1V; $f$ is the frequency of pulse, related to the type of pulse generation; $\phi$ is the initial phase. From the perspective of impact on communication quality, according to the stationary and non-stationary characteristics of power line noise, the above noise can be divided into two types: background noise and impulse noise. Background noise changes slowly with time, including colored background noise, narrow-band noise, and periodic impulse noise synchronized to the power frequency. Impulse noise has strong time-varying characteristics, the power spectral density rises suddenly when pulse appears, including periodic impulse noise asynchronous to the power frequency and random impulse noise.

Based on the above power line noise model, this paper simulates the carrier signal of its communication process. As shown in Figure 1, (a) is binary symbol sequence $s(t)$, (b) is carrier signal modulated and superimposed with power line mixed noise. The interfered power line carrier signal has become difficult to identify.

Discretize and sample the above-mentioned signal, the frequency spectrum after Fourier transform is shown in Figure 2. The decomposed frequency packet of mixed signal is composed of main frequency components centered at 421KHz and secondary components uniformly distributed throughout the frequency spectrum. The main frequency components come from power line carrier frequency modulation signal and power line noise component in this frequency band. The carrier frequency has been selected to avoid the frequency band with high noise spectral density. Therefore, by decomposing the main frequency components in the mixed signal and removing the uniformly distributed frequency components, can achieve effective noise reduction of carrier communication signal.

3. LVPLC noise reduction algorithm
Through the analysis of power line noise characteristics, it can be known that the noise reduction of power line carrier signals can be converted into signal frequency domain separation problem.
Since any time-domain signal can be transformed into periodic signals of different frequency components through Fourier decomposition, and the decomposed periodic signal can fully reflect the amplitude-frequency characteristics and phase-frequency characteristics of the original signal. Therefore, this paper chooses the Fourier decomposition method to perform frequency domain conversion on mixed signal.

![Fig.1 Noisy signal](image1)

![Fig.2 Spectrum of noisy signals](image2)

Within a certain period, the power line mixed sampling signal \( x(t) \) is a discrete signal with finite length, decompose this mixed signal by Discrete Fourier Transform (DFT).

\[
DFT_x(\omega) = X(\omega) = \sum_{n=-\infty}^{\infty} x_n e^{-j\omega n}
\]

(3)

From the above analysis of power line carrier noise characteristics, background noise with low power spectral density is evenly distributed throughout the frequency spectrum, impulse noise has a small component in the carrier frequency band, and the frequency points with large mixed signal amplitudes are concentrated near the carrier frequency band.

Therefore, in the process of frequency domain separation of mixed signals, in order to realize the separation of main frequency components, four steps are required to complete:

1. In the carrier frequency estimation stage, the power line mixed sample signal \( x(t) \) is Fourier decomposed into \( X(\omega) \), select frequency \( f_0 \) with the largest amplitude as carrier frequency;
2. In the main frequency component separation stage, retain the frequency components in the carrier frequency range with \( f_0 \) as center frequency point and \( W \) as bandwidth in \( X(\omega) \). Other frequency components are set to zero, the separated \( X(\omega) \) is recorded as \( X'(\omega) \). The selection of \( W \) is related to actual carrier receiver performance requirements;

\[
X'(\omega) = \begin{cases} 
X(\omega) & f_0 - 0.5W < \omega < f_0 + 0.5W \\
0 & \text{other}
\end{cases}
\]

(4)

3. Construct a multi-frequency band stop filter for noise frequency components to reduce noise;
4. In the signal frequency domain recovery stage, perform inverse Fourier transform on signal \( X'(\omega) \) to obtain power line carrier signal \( x'(t) \) after frequency domain noise reduction:

\[
x'(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} X'(\omega)e^{j\omega t} d\omega
\]

(5)

After the above steps, the components of power line carrier mixed signal with a large difference in frequency from the carrier signal can be filtered out.

4. Experimental simulation analysis
In order to verify the effectiveness of the proposed method in this paper, we conducted experiments to verify the new method of low-voltage power line carrier signal frequency domain noise reduction method. The power line carrier signal adopts amplitude shift keying (ASK) and phase shift keying (FSK)
modulation methods respectively. Compare the time-frequency hybrid noise reduction method proposed in this paper with denoising method based on multi-resolution wavelet packet mentioned in literature [9-10]. Perform performance comparison analysis in the same scene.

For power line carrier mixed signals under different modulation methods, the time-frequency hybrid noise reduction method proposed in this paper has achieved good denoising results, as shown in Figure 3 1(d) and 2(d), verify our algorithm has effectiveness and practicality.

In order to verify the noise reduction effect of our method under different noise scenarios, use the observational data of power line noise from a certain city’s radio station. It adopts amplitude shift keying (ASK) modulation method, which has a low noise environment and noise characteristics of power line during peak power consumption. The original carrier symbol signal is shown in Figure 4(a). In low-noise environment, the noise in low-voltage power line network is mainly background noise. In order to simulate the communication process under real working conditions, based on the above low-voltage power line noise modeling analysis, the mixed signal waveform is shown in Figure 4(b).

Since the level amplitude of background noise is less than 0.2V, the energy carried by noise signal is lower than power line signal. The effect of using the multi-resolution wavelet packet noise reduction method in the literature [9-10] is shown in Figure 4(c), the SNR conversion amount is $\Delta \text{SNR}=4.5\text{dB}$; the effect of noise reduction on the noise-containing mixed signal using our method is shown in Figure 4(d), it can eliminate the low-frequency components well, and has good amplitude and symbol width characteristics, the SNR conversion amount is $\Delta \text{SNR}=5.2\text{dB}$.

In order to reflect the carrier noise reduction effect of our algorithm when the channel conditions are bad, we conduct simulation based on the sampled data during peak power consumption. There are more impulse noises in power line network during peak power consumption. From the above, the amplitude of impulse noise is larger than background noise, mostly between 0.4V and 1V. The original carrier signal has strong interference and SNR is high. The power line carrier signal observation data is shown in Figure 5(b), and the boundary between 0 and 1 in carrier signal becomes blurred. The effect of using the multi-resolution wavelet packet noise reduction method in the literature [9-10] is shown in Figure 5(c), the SNR conversion amount is $\Delta \text{SNR}=5.75\text{dB}$; the noise reduction effect of our algorithm is shown in Figure 5(d), still retain good waveform characteristics, the SNR conversion amount is $\Delta \text{SNR}=9\text{dB}$. 

![Fig.3 Noise reduction effect of different modulation methods](image-url)
5 Conclusion
This paper proposes a new frequency domain noise reduction method for low voltage power line carrier communication in the communication interactive process of power information acquisition system of intelligent power distribution system. By using actual low-voltage station area carrier communication signals, we conduct experiments under normal conditions and poor channel conditions respectively to verify the effectiveness and practicability of our method in low-voltage power line carrier signal noise reduction.

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