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Peak-type Markov Chain Modeling of the Noise in Voltage Power Line Communication Channel Based on Pulse-group

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Abstract: Noise interference is one of the main factors affecting the reliability of low-voltage power line communication. In response to the shortcomings of noise models studied by scholars both domestically and internationally in recent years, an improved model was developed for a class of noise with its own characteristics. A low voltage power line noise peak Markov chain model based on pulse swarm was established, and simulation verification was conducted. The simulation results show that as long as the amplitude, width, and interval states of the noise are sufficient, and the threshold settings for pulse group width and interval are reasonable, the reconstructed low-voltage power line communication channel noise from the model has a high degree of similarity and even basic consistency compared to the actual measured noise, providing a practical and feasible solution for future power line communication channel noise modeling problems.

1. Introduction

Low-voltage power line communication (LPLC) technology refers to the communication technology that uses low-voltage (220/380V) distribution line as the communication medium to realize data, voice, image and other integrated services transmission [1]. However, the low-voltage power line is not a dedicated communication channel, and the noise interference in the channel is more complex than other communication channels. Noise will increase the signal error rate, reduce the communication quality, and even lead to complete failure of the communication [2].

The noise in low-voltage power lines can be divided into background noise and impulse noise [3, 4]. In terms of background noise, literature [5] proposes that the background noise model can be obtained by passing a set of white noise through the AR model, and literature [6] and literature [7] use different calculation methods to obtain its AR model parameters, but this model can only be verified from the frequency domain, and it is difficult to recover its time domain waveform, so it cannot intuitively reflect the correctness and accuracy of the model. In terms of impulsive noise, literature [8] and literature [9] proposed a impulsive noise model based on clustering Markov chain. However, this method ignores the correlation between the amplitude, width, interval and symbol of pulse noise, so the time domain waveform of pulse noise simulated by this model is quite different from the real pulse noise waveform. Literature [10] and literature [11] proposed a pulse noise model based on peak Markov chain. However, this method ignores the objective fact that impulse noise does not exist at all times, but occurs as a group of pulses due to some sudden conditions. Therefore, the time domain waveform of impulse noise simulated by this model is different from the real impulse noise waveform.

This article proposes a method for modeling low voltage power line noise peaks using Markov chains based on pulse swarm analysis based on measured noise data. The simulation results show that in modeling such noise, the model overcomes the shortcomings of relevant literature and obtains a simulation model with minimal error compared to the measured noise, and its time-domain waveform also has high similarity.

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2. Analysis of Measured Noise

The noise measurement block diagram of the low-voltage power line communication channel is shown in Figure 1. The noise is coupled to the storage oscilloscope through a coupling network based on an inductance coupler, and the noise data is obtained from the storage oscilloscope and stored before being transmitted to the computer for analysis.

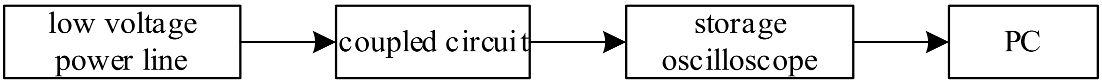

Fig.1 The measurement block diagram of back noise

Observe a series of measured noise and select a type of noise pattern with its own characteristics, as shown in Figure 2, which is one of the wave forms. One peak shaped noise can be regarded as a group of pulse noise. These pulse noise groups, like noise, have their widths and intervals, and these widths and intervals are almost identical in each group of noise. Imagine adding the width and interval of the pulse noise group to the establishment of the noise peak Markov chain model, and the pulse noise in the constructed noise will also appear in the form of the pulse noise group, just like the actual situation. This way, the established model is more in line with the actual situation, and the time-domain waveform will inevitably have higher similarity.

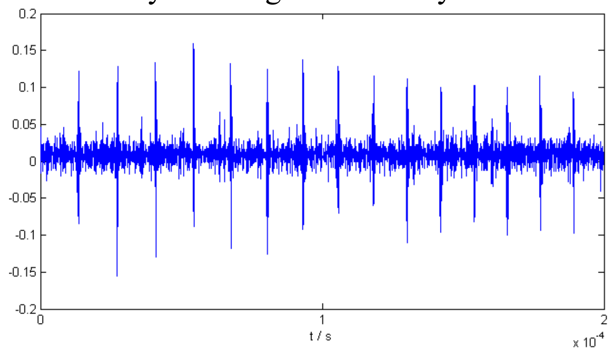

Fig.2 The measured power line noise

3. Noise Modeling

Consider the individual noise within each pulse noise group as discrete states, and model them into 10 states based on their amplitude, width, and interval sizes.

Observing the part within the pulse group in the measured noise (Figure 2), the state transition of amplitude cannot be described by a simple Markov chain. It is found that the amplitude within each pulse group changes first and then decreases, and peak Markov chains should be used to describe it; And as the pulse amplitude increases, the pulse width and interval show a decreasing trend.

Combining the above laws with the definition of peak Markov chains, it can be further described as follows: the amplitude of k+1 is not only related to the amplitude of k, but also to the amplitude of k-1: if the amplitude of k is greater than the amplitude of k-1, the probability of the amplitude of k+1 being greater than the amplitude of k is significantly higher than the probability of the amplitude of k+1 being less than the amplitude of k; If the amplitude at time k is less than the amplitude at time k-1, the probability of the amplitude at time k+1 being greater than the amplitude at time k is significantly lower than the probability of the amplitude at time k+1 being less than the amplitude at time k. The amplitude at time k+1 is not only related to the amplitude at time k, but also to the magnitude of the amplitude between time k and time k-1.

Using the peak Markov chain to statistically analyze the measured pulse noise, the two sets of transfer matrices for the amplitude of noise within the pulse group are obtained as follows:

$$P_1 = \begin{bmatrix} 0.6859 & 0.1793 & 0.0607 & 0.0459 & 0.0133 & 0.0059 & 0.0059 & 0.0030 & 0 & 0 \\ 0.4879 & 0.2249 & 0.1073 & 0.0761 & 0.0588 & 0.0242 & 0.0104 & 0.0069 & 0 & 0.0035 \\ 0.3333 & 0.1824 & 0.2201 & 0.1258 & 0.0629 & 0.0252 & 0 & 0.0189 & 0.0252 & 0.0063 \\ 0.2481 & 0.2180 & 0.2180 & 0.1353 & 0.1053 & 0.0526 & 0.0226 & 0 & 0 & 0 \\ 0.1778 & 0.2333 & 0.2333 & 0.2111 & 0.0889 & 0.0444 & 0.0111 & 0 & 0 & 0 \\ 0.1556 & 0.2000 & 0.2444 & 0.0444 & 0.1333 & 0.1111 & 0.0444 & 0.0667 & 0 & 0 \\ 0.1034 & 0.1379 & 0.1034 & 0.1724 & 0.2414 & 0.2069 & 0.0345 & 0 & 0 & 0 \\ 0.0714 & 0 & 0.0714 & 0.3571 & 0.2857 & 0.1429 & 0.0714 & 0 & 0 & 0 \\ 0 & 0 & 0.1429 & 0.1429 & 0.5714 & 0.1429 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.3333 & 0.6667 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$P_2 = \begin{bmatrix} 0.6188 & 0.1935 & 0.0587 & 0.0528 & 0.0323 & 0.0117 & 0.0264 & 0 & 0.0029 & 0.0029 \\ 0.3817 & 0.2824 & 0.1221 & 0.0611 & 0.0611 & 0.0382 & 0.0153 & 0.0229 & 0.0153 & 0 \\ 0.2658 & 0.3418 & 0.1899 & 0.1392 & 0.0633 & 0 & 0 & 0 & 0 & 0 \\ 0.3571 & 0.2381 & 0.1190 & 0.1190 & 0.0714 & 0.0476 & 0.0238 & 0.0238 & 0 & 0 \\ 0.0417 & 0.0417 & 0.2500 & 0.2917 & 0.2083 & 0.0833 & 0.0833 & 0 & 0 & 0 \\ 0.2222 & 0.1111 & 0.2222 & 0.1111 & 0.1111 & 0.1111 & 0.1111 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1.0000 & 0 & 0 & 0 & 0 & 0 & 0 \\ NaN & NaN & NaN & NaN & NaN & NaN & NaN & NaN & NaN & NaN \\ NaN & NaN & NaN & NaN & NaN & NaN & NaN & NaN & NaN & NaN \\ NaN & NaN & NaN & NaN & NaN & NaN & NaN & NaN & NaN & NaN \end{bmatrix}$$

Among them, P1 represents the probability of transition when the amplitude at time k is greater than the amplitude at time k-1; P2 is the probability of a transition where the amplitude at time k is less than the amplitude at time k-1 (NaN means it does not exist, meaning it is impossible to obtain a higher amplitude when the previous two amplitudes are decreasing).

Establish a transfer matrix between amplitude and width as follows:

$$P_3 = \begin{bmatrix} 0.2578 & 0.2436 & 0.0803 & 0.1445 & 0.1265 & 0.1058 & 0.0331 & 0.0057 & 0.0019 & 0.0009 \\ 0.3434 & 0.3155 & 0.0812 & 0.0789 & 0.0974 & 0.0650 & 0.0139 & 0 & 0.0023 & 0.0023 \\ 0.3840 & 0.3954 & 0.0837 & 0.0684 & 0.0456 & 0.0152 & 0.0038 & 0.0038 & 0 & 0 \\ 0.5368 & 0.3474 & 0.0684 & 0.0263 & 0.0053 & 0.0158 & 0 & 0 & 0 & 0 \\ 0.4874 & 0.4202 & 0.0588 & 0.0084 & 0 & 0.0252 & 0 & 0 & 0 & 0 \\ 0.4921 & 0.4444 & 0.0635 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.6250 & 0.3438 & 0 & 0.0313 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.7143 & 0.2857 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.8889 & 0.1111 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1.0000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Establish a transition matrix between amplitude and interval as follows:

$$P_4 = \begin{bmatrix} 0.3900 & 0.3447 & 0.1360 & 0.0567 & 0.0293 & 0.0161 & 0.0142 & 0.0113 & 0 & 0.0019 \\ 0.7077 & 0.2413 & 0.0278 & 0.0093 & 0.0093 & 0.0023 & 0.0023 & 0 & 0 & 0 \\ 0.7757 & 0.2053 & 0.0152 & 0 & 0 & 0 & 0.0038 & 0 & 0 & 0 \\ 0.8684 & 0.1316 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.9412 & 0.0588 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.9524 & 0.0476 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.9375 & 0.0625 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1.0000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1.0000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1.0000 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

The relationship between interval and symbol change probability is established as follows:

$$P_5 = \begin{bmatrix} 1.0000 & 0.4214 & 0.5188 & 0.5313 & 0.3714 & 0.4444 & 0.5294 & 0.5833 & 0 & 0.5000 \end{bmatrix}$$

Outside the pulse group, most of the noise is background noise, and its amplitude does not have the general characteristics of peak Markov chains. Therefore, traditional Markov chains can be used for modeling.

Using traditional Markov chains to statistically analyze the measured pulse noise, the transfer matrix of the amplitude of noise outside the pulse group is obtained as follows:

$$P_6 = \begin{bmatrix} 0.6683 & 0.1812 & 0.0613 & 0.0460 & 0.0188 & 0.0098 & 0.0105 & 0.0028 & 0.0007 & 0.0007 \\ 0.4682 & 0.2385 & 0.1095 & 0.0654 & 0.0583 & 0.0247 & 0.0194 & 0.0088 & 0.0053 & 0.0018 \\ 0.3249 & 0.2240 & 0.2019 & 0.1199 & 0.0631 & 0.0284 & 0 & 0.0126 & 0.0221 & 0.0032 \\ 0.2596 & 0.2085 & 0.2043 & 0.1404 & 0.1021 & 0.0553 & 0.0213 & 0.0043 & 0.0043 & 0 \\ 0.1605 & 0.1975 & 0.2346 & 0.0741 & 0.1605 & 0.0864 & 0.0494 & 0.0370 & 0 & 0 \\ 0.1429 & 0.1190 & 0.0952 & 0.1905 & 0.2619 & 0.1667 & 0.0238 & 0 & 0 & 0 \\ 0.0588 & 0 & 0.0588 & 0.4118 & 0.2353 & 0.1765 & 0.0588 & 0 & 0 & 0 \\ 0.0714 & 0 & 0.0714 & 0.3571 & 0.2857 & 0.1429 & 0.0714 & 0 & 0 & 0 \\ 0 & 0 & 0.1667 & 0.1667 & 0.5000 & 0.1667 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.3333 & 0.6667 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

4. Simulation Comparative Analysis

Using the established power line channel pulse group internal noise model and pulse group external noise model, a threshold of pulse group interval and width is set to synthesize power line noise in the time domain. Due to the randomness of the Markov chain model and the settability of pulse group interval and width threshold values, countless sets of noise that conform to this model can be constructed for research. Figure 3 shows the power line noise constructed by one set. Observing the time-domain waveform of power line noise constructed in this article, compared with the waveform constructed in reference [11], it has a higher similarity with the measured power line noise, reflecting the existence of pulse groups, which is consistent with the actual situation of pulse occurrence. If the current "amplitude, width, and interval are divided into 10 states" are extended to more states, the constructed power line noise will inevitably become closer to the actual noise, as shown in Figure 4, which is the simulation diagram when extended to 91 states, and there is no significant difference from the measured waveform, with extremely high accuracy.

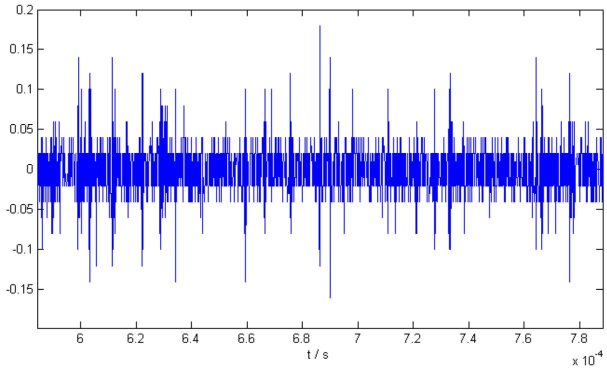

Fig. 3 One group of the structured power line noise

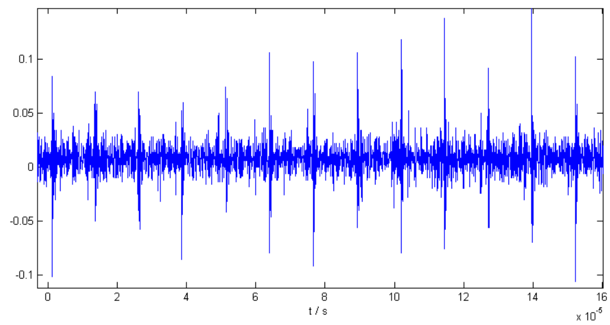

Fig. 4 Comparison of Simulated and Measured Waveforms at 91 States

5. Conclusion

Noise interference is one of the main factors affecting the reliability of power line communication, and there is currently no clear standard. Therefore, the study of its model has important theoretical and practical significance. This article focuses on the shortcomings of research by domestic and foreign scholars in recent years, and improves it by establishing a low voltage power line noise peak Markov chain model based on pulse swarm, and conducting simulation verification. The simulation results show that as long as there are enough states divided and the threshold settings for pulse group width and interval are reasonable, the established low-voltage power line communication channel noise has a greater similarity compared to the actual measured noise (when divided into 91 states, there is no significant difference from the measured waveform), providing a practical and feasible solution for future low-voltage power line communication channel noise modeling problems.

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