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The time-domain model of 10kV power Line communication based on OFDM

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Abstract. The signal noise and attenuation in channels severely affect the communication quality in power distribution network. Orthogonal Frequency Division Multiplexing(OFDM) has an excellent antijamming capability and a high rate of channel utilization and is widely adopted in power line communication. In this paper, an OFDM system applied in power line communication is established. Then several typical channel models under Matlab are chosen to simulate the signal transmission in 10kV power line communication and analyze the channel characteristics.

INTRODUCTION

Power line communication is a special kind of communication mode which uses the power line as the signal transmission medium. In recent years, a growing recognition to power line communication is given with the increase of social demand. However, power line, originally designed for electric power distribution, is not an ideal signal transmission medium. Also, it is susceptible to the interference in signal transmission. OFDM is a modulation technique which enables high transmission rate, the effective utilization rate of spectrum and the ability of strong resistance to sudden interference. In addition, it ensures stable and reliable signal transmission with channel coding, FFT and window technique. The paper selects typical channel models(Multipath model, AR model and FIR model) to build time domain model of 10kV power line communication based on OFDM. Finally, the paper analyzes the transmission characteristics in the communication under different models and has practical significance.

ESTABLISHMENT OF OFDM

Basic principles

The basic idea of OFDM is that a given channel is divided into many orthogonal sub-channels on which the parallel subcarrier is modulated. In this way, although the overall channels with frequency selection characteristic are uneven, each sub-channel is a narrow-band transmission one and the signal bandwidth is less than corresponding channel bandwidth. Thus the interference between the signal waveform is greatly eliminated . Since OFDM allows the subcarrier frequency spectrum aliasing, the data can be separated from the mixture of subcarrier signal if the subcarrier is orthogonal to each other and its spectrum efficiency is greatly increased.

Building process

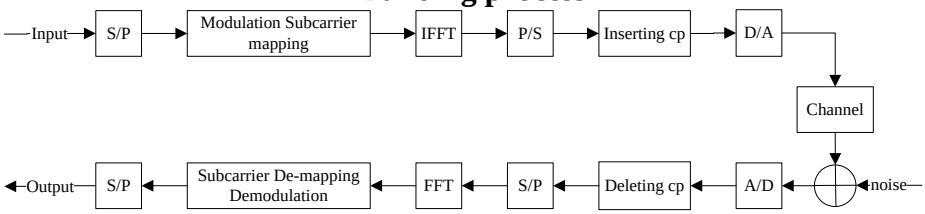


FIGURE 1. Communication system of OFDM

(1) Coding and decoding: To prevent the signal interfere, the paper selects the Convolution coding and Vitdec decoding.

(2) Weaving: Weaving is used to reduce the burst error in the data channel. The mixed data

through a series of parallel converter is mapped to the corresponding constellation diagram.

(3) Modulation: OFDM has many ways to modulate, including BPSK, QPSK, QAM and etc. This paper adopts the QPSK to analyze.

(4) Inserting pilot frequency: Four pilot frequencies are inserted into every 48 subcarriers in the paper for stability of received data and transmission efficiency.

(5)Serial/parallel conversion: Signal's serial/parallel conversion coordinates with IFFT/FFT to improve the transmission efficiency.

(6) FFT/IFFT: The transmission of data between time domain and frequency domain is achieved by FFT/IFFT.

(7) Inserting cyclic prefix: To maximize the elimination of inter-symbol interference, the cyclic prefix is inserted in OFDM to reduce multipath time delay.

TIME DOMAIN MODEL OF 10KV POWER LINE COMMUNICATION

Power line channel modeling

Power line channel, used as medium in power distribution network, plays an vital role in the realization of the communication. Its frequency ranges from 40kHz to 500 kHz. The negative impact on power line communication is summarized into 3 aspects: changeable impedance characteristics, attenuation and noise characteristics.

Impedance characteristics

The efficiency of signal coupling is effected by power line impedance. Moreover, the time-varying loads and complex branch lines increase the difficulty of the impedance matching. Through actual measurement, we find that the impedance characteristics of 10 kV power line varies as the measuring distance and frequency change, but is not sensitive to time. With the increase of frequency, the input impedance presents the rising trend. Typically, the impedance is relatively small under the frequency below 100kHz. All this requires that the equipment should have a low output impedance to achieve the impedance matching and improve transmission efficiency.

Attenuation characteristics

The signal attenuation on power line, which is influenced by communication distance and frequency, can be divided into lines and coupling decay. Generally speaking, the higher the frequency is, the worse the attenuation is. For some specific frequency, the resonance phenomenon caused by loads and transmission line effect even makes the attenuation increase rapidly. The attenuation of 10 kV power line also appears obvious frequency selection characteristics. Also, transmission attenuation at specific frequency and branch line attenuation are the factors for the decline in communication quality. Multipath effect caused by branch points and instantaneous charging current in a circuit will cause serious signal attenuation. Therefore choosing an appropriate modulation method is particularly important.

Noise characteristics

The noise interference in 10 kV power line is one of the major problems restricting the reliable data transmission. The noise can be classified into background noise and impulse noise. The background noise, produced by the noise source of low power, usually decreases with the increased frequency, whose power spectral destiny(PSD) keeps stable under different frequencies in a certain period. Their effect on communication system is mainly connected with the average signal to noise ratio(SNR),the equipment on the grid and the frequency distribution of radio transmitter. The impulse noise, whose PSD is higher, often changes with time in milliseconds or microseconds. The bit error and burst error of data transmission in power line communication is mainly caused by impulse noise.

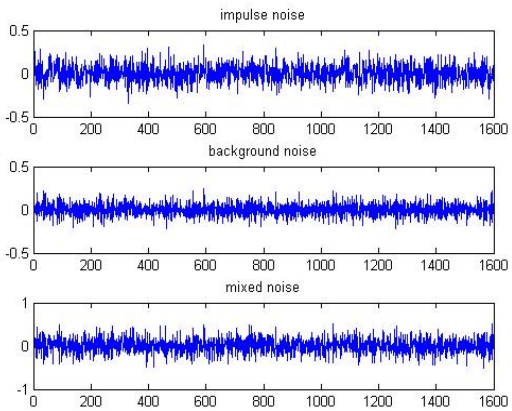


FIGURE 2. The simulation of noise in Matlab

Channel estimation

In the complex transmission environment, the time-frequency domain response of the channel is time-varying. The frequency selection attenuation caused by multipath effect also appears inconsistent on different sub-carriers. Consequently, the individual data sub-carrier in OFDM distorts unevenly. To protect the system's performance from channel multipath and attenuation effect and obtain the performance gains of coherent detection, channel estimation is required to track the change of the response and correct the received data. Maximum channel delay, the noise of the receiver and insertion mode of pilot frequency are the important factors for the channel estimation algorithm performance. This paper adopts MMSE channel estimator for channel estimation.

If vector H with Gaussian random feature and noise vector N are independent of each other, the estimation of H based on the minimum mean square error (MMSE) criterion is as follows, in which R_{hh} represents the covariance matrix of time domain channel vector.

$$\hat{H}_{MMSE} = FQ_{MMSE}F^{H}X^{H}Y \tag{1}$$

$$Q_{MMSE} = R_{hh}\left[\left(F_H X_H XF\right)^{-1}\delta^2 + R_{hh}\right]^{-1}\left(F_H X_H XF\right)^{-1} \tag{2}$$

10KV POWER LINE CHANNEL TRANSMISSION MODEL

Multipath model

Power line channels are mainly multipath channels with frequency selection and attenuation characteristics. Using the "top-down" modeling method, the channel is regarded as a black box and the related parameters in the model are obtained from the field measurement data. Assumed that the signal frequency range from 500KHz to 20 MHZ, the 10kV power line channel model is established. The frequency response function is expressed as

$$H(f) = \sum_{i=1}^{N} g_i A(f, d_i)\ e^{-j2\pi f \tau_i} \tag{3}$$

In the formula, i is the path number; g is the weighted coefficient of path i; $A(f, d_i)$ is the attenuation coefficient of path i ,whose value is decided by path length and frequency; $A(f, d_i)\ e^{-(\alpha_0+\alpha_1 \mathrm{fk})\ d_i}$ reflects the transmission characteristics of power line in multipath model.

However, the multipath model is the fitting of channel’s frequency response just for one moment and cannot reflect its random variation characteristics.

AR model

For an established power line channel, its frequency response is a slow change of stochastic process. The autoregressive theory indicates that the random process can be regarded as the

output of white noise process through a specific filter. If the filter's coefficients are given correctly, the complicated stochastic process can be described with limited parameters. These conclusions can also be used in 10kV power line channel modeling. The maximum order of filter is determined by maximum time delay and signal element between A and B.

AR model can not only reflect the frequency selection and attenuation characteristics of channel, it also reflects the time-varying characteristics. However, the model lacks the reliable physical significance.

FIR model

Assume that the signal transmits from A to B on power line, the received signal at B can be seen as the signal superposition from A after different time delay and attenuation. The theory can be realized by FIR filter, which is shown below.

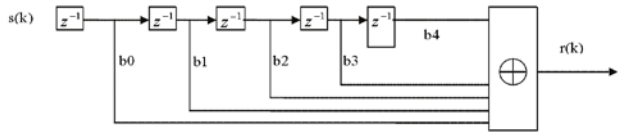


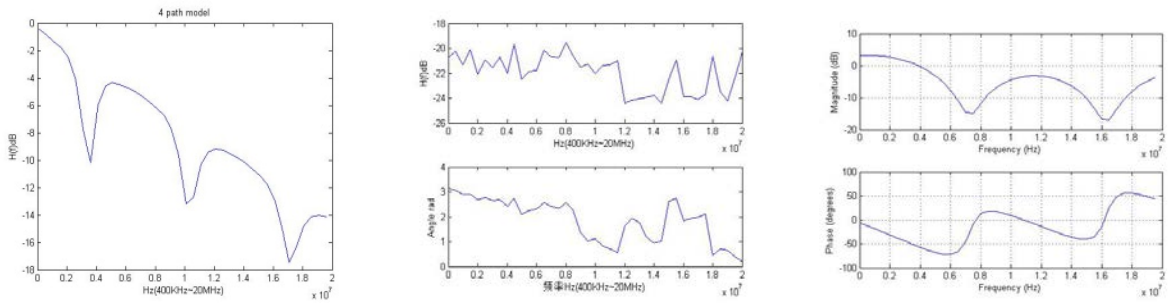
FIGURE 3. The structure of FIR filter

The response of filter is expressed as

$$r(n)=\sum_{k=0}^{N-1}h(k)s(n-k) \tag{4}$$

If the order and filter coefficients are selected properly, the FIR model can indicate the frequency attenuation of power line channel accurately. The model obtains the received signals directly but cannot reflect the time-varying characteristics of channel.

Figure 5-12,5-13,5-14 indicate the frequency response of multipath(4paths) model, AR model and FIR model.

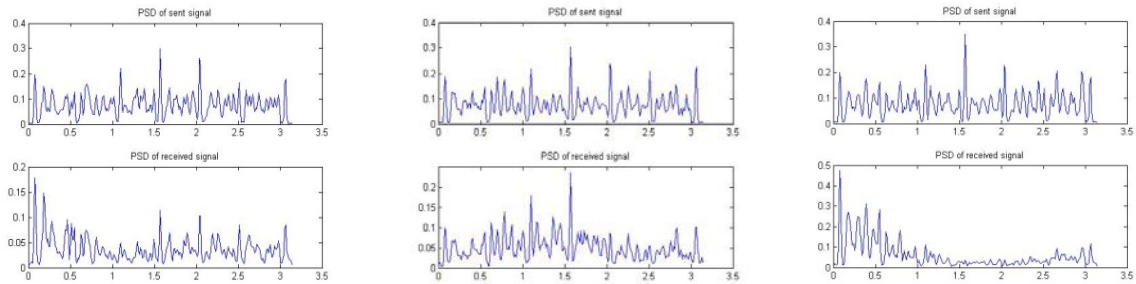


(a)Multipath model (b)AR model (c)FIR model

FIGURE 4. The simulation of transmission characteristics

SIMULATION OF 10KV POWER LINE COMMUNICATION

Generate random signal and transmit the modulated signal after OFDM through power line channels. The power attenuation characteristics under different channel models are shown below.



(a)Multipath model (b)AR model (c)FIR model

FIGURE 5. Attenuation characteristics of channels

From the figures above, we find that under multipath model, the signal's PSD declines at all the spectrum through the channel; under AR model, the signal's PSD declines more at low and intermediate frequency and less at high frequency; under FIR model, selecting the low pass filter, the signal's PSD remains unchanged at low frequency and declines at intermediate and high frequency.

CONCLUSION

The paper analyzes the principles and key techniques of OFDM and establishes the OFDM system. The time domain model of. Several typical channel models is selected to simulate communication in 10kV power line communication based on OFDM. The model analyzes the transmission characteristics of power line under diverse models and enables different signal processing techniques. The model is of great universality.

However, OFDM technique itself has some shortcomings, such as complicated technology or a poor performance when a great attenuation or noise appears in the channel. The improvement of its stability will be the further research direction.

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