Design of All-Pass Filter System for Power Communication with High Anti-harmonic Interference

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Abstract. In the traditional system, the prediction sensing unit was lacking, which caused the output voltage and current harmonic content to deviate greatly from the actual value. In order to solve this problem, the design of the all-pass filtering system for power communication with high anti-harmonic interference was proposed. According to the hardware structure block diagram of the system, the predictive sensing module was designed to obtain readable and unreadable information. In order to make the system only transmit readable information, the closed switch was designed, and the client module at the end of the hardware was set to display the prediction results and improve the harmonic interference problem; For the above system hardware control module, the software part was designed, and the filter system function was determined according to the software design flow, thereby completing the design of the all-pass filter system for power communication with high anti-harmonic interference. The experimental results showed that the output voltage and current harmonic content of the system were consistent with the actual value, which provided a certain reference for the filter anti-interference.

Keywords: High anti-harmonic interference · Power communication · All-pass filter · Perception · Prediction

1 Introduction

Data communication through power lines is undoubtedly an economical and convenient way, but in the transmission of signals in the power grid, the background must contain a large number of power grids and their harmonic components to drown the communication signals, bringing great difficulty to the detection. Generally, an all-pass filter is used to eliminate one or more harmonic interferences in the signal without affecting the frequency components of the communication signal, thereby improving the detection signal-to-noise ratio [1]. A filter is a frequency selective network that transforms an input signal into a desired output signal in a prescribed manner, allowing signals of certain frequencies to pass through to block or attenuate signals of other frequencies. The theory and technology of filters have been steadily developing rapidly.

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It has been widely used in various electronic devices. Without the penetration of filters into electronic technology, there is no modern electronic world [2].

At present, it is common practice to suppress a certain harmonic interference component by a second-order notch with an all-zero point and an all-pole cascade, or to design a single-frequency point trap by a second-order all-pass filter, and then The suppression of multiple harmonic interferences is achieved by cascading [3]. Literature [4] proposed All-Pass-Filter-based Active Damping for VSCs with LCL Filters Connected to Weak Grids. Based on making the open loop phase at the resonant frequency zero. This strategy will be shown to provide sufficient oscillation damping and can be implemented in two different ways: at the design stage (if design constraints make it possible) or an all-pass filter in series with the current controller.

Literature [5] proposed Design and Simulation of the Integrated Navigation System based on Extended Kalman Filter. The structure of the INS/GPS integrated navigation system consists of four parts, namely GPS receiver, inertial navigation system, extended Kalman filter and integrated navigation scheme. We then illustrate how to use the extended Kalman filter to simulate an integrated navigation system by measuring position, velocity and attitude. In particular, an extended Kalman filter can estimate the state of a nonlinear system in a noisy environment. In the extended Kalman filter, the estimation of the state vector and the error covariance matrix is calculated by the following steps: (1) time update and (2) measurement update. Finally, the simulation process is implemented by Matlab.

However, due to the influence of the coefficient quantization effect, these filters have higher sensitivity, especially in the low frequency band, making the notch frequency point easily offset. In the background noise of the power line communication signal, the largest components such as the 3rd and 5th harmonics of the fundamental wave are in the low frequency band relative to the acquisition frequency. Whether the interference components can be accurately filtered out will directly affect the communication quality. In the medium voltage large-capacity variable frequency drive device, in order to solve this problem, a high-pass filter system design for power communication with high anti-harmonic interference is studied, because the numerator and denominator polynomial of the all-pass filter transfer function are mirrored. The symmetry relationship makes the filter have the lowest coefficient sensitivity in the low frequency band and can obtain an efficient lattice operation structure.

2 Hardware Design of All-Pass Filter System

According to the characteristics of harmonic interference, the overall structure block diagram of the all-pass filter system under this condition is designed, as shown in Fig. 1.

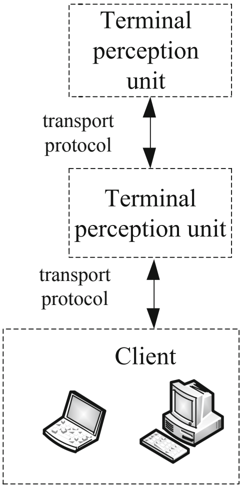


Fig. 1. System overall structure

It can be seen from Fig. 1 that the overall structure of the system is mainly composed of the terminal sensing unit, the control unit and the client. The terminal sensing unit is mainly responsible for monitoring the information parameters and intelligently controlling the monitoring switch. The control unit is mainly responsible for transmitting the network terminal parameters collected by all nodes to the filtering server, and issuing a command signal to the relevant node server; The client is mainly responsible for real-time monitoring of network terminal information monitoring results and remote monitoring, and automatically controls the filters in the intelligent control priority control unit.

2.1 Predictive Perception

The predictive sensing module is mainly responsible for predicting and sensing the data information transmitted during the power communication process. The module uses the Kalman filter prediction method to realize the two-way intelligent communication of the predicted information in the power communication process. When the collected data information is transmitted to the control unit through the prediction sensing module, it needs to pass five nodes, which are the system total power switch node, the sensing node, the collecting node, the processing node and the receiving node, between the five nodes. The relationship is shown in Fig. 2.

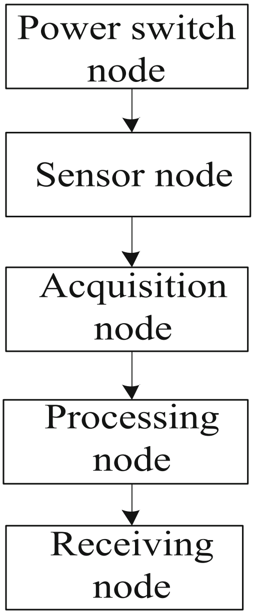


Fig. 2. Predictive perception framework

It can be seen from Fig. 2 that in addition to the harmonic interference prediction sensing information, the above five nodes also include readable information and unreadable information. The sensing node monitors readable and unreadable information to ensure that each data information has a specific attribute; The collection node collects the system operation data in real time; the receiving node acquires the data information from the collection node; the processing node processes the received information [6].

2.2 Control Unit

The control unit is composed of a wireless sensor coordinator and a network server. When predicting harmonic interference, it is necessary to accurately transmit the data transmitted by the device, and the generation of the sensor data needs to be controlled by a switch [7]. In order to make the control effect better, a closed switch with readable and unreadable information is designed, as shown in Fig. 3.

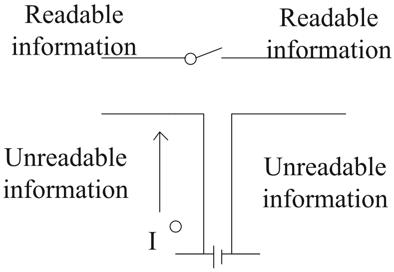


Fig. 3. Readable and unreadable information closure switch

The closed switch shown in Fig. 3 is designed in a reverse connection manner, with one node as a voltage input value and a current value with a positive characteristic in the loop. The readable information and the unreadable information are simultaneously transmitted to the circuit, and the data information collected by all the nodes is transmitted to the host through the wireless sensor coordinator, and the readable information is transmitted [8].

2.3 Client Module

The client module is set at the end of the hardware, which is mainly responsible for displaying the harmonic interference prediction result, and the staff can view the network terminal data prediction result in real time through the client interface. The system prediction switch is a key part of the overall hardware structure design. The server at the front end of the client uses the error-free and non-repetitive information prediction of the data, and the client data is transmitted according to the TCP protocol [9]. Since the data information generated by the power communication is different, it is necessary to fully consider the transmission condition of the signal, and use the wireless sensing device to securely transmit the node information to ensure the security of the data information transmission. The client interface settings are shown in Fig. 4.

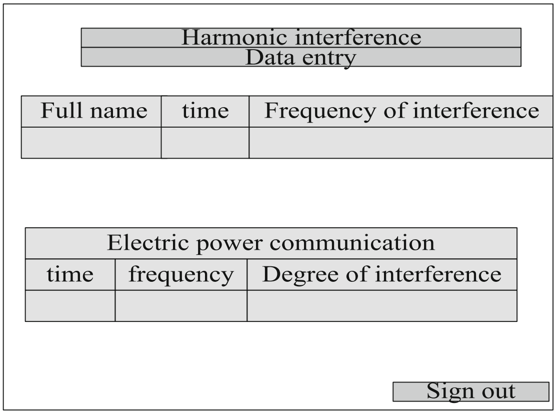


Fig. 4. Client interface settings

The design of the system hardware structure adopts the Kalman filter prediction method to realize the fast perception of the prediction information, thereby obtaining readable and unreadable information. In order to make the system only transmit readable information, it is necessary to design a closed switch to make the data communication better. The client module is set at the end of the hardware, which is mainly responsible for displaying the communication result, and the athlete can view the data communication result of the network terminal in real time through the client interface.

3 System Software Part Design

For the above system hardware control module, the software part is designed, as shown in Fig. 5.

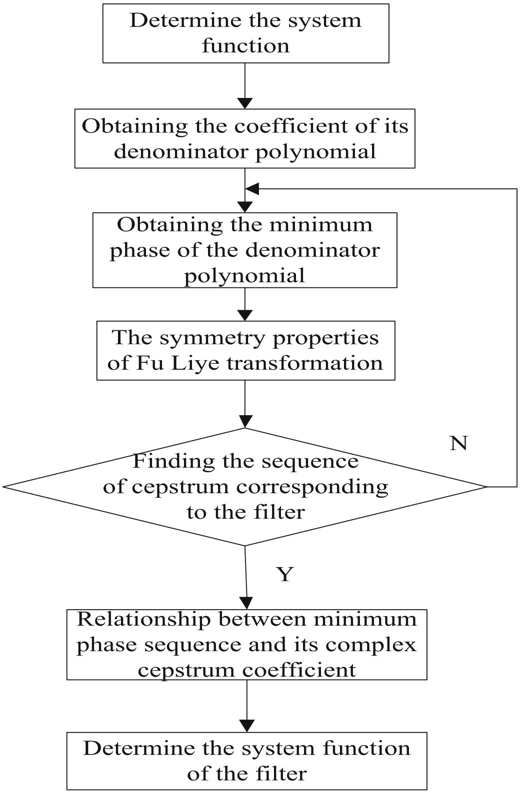


Fig. 5. System software design process

The system function of the digital all-pass filter can be obtained from Fig. 5:

$$F(x) = \frac{A(x)}{B(x)} = \frac{\sum_{m=0}^{M} q_{M-m}^{x^{-m}}}{\sum_{m=0}^{M} q_{m}^{x^{-m}}} \tag{1}$$

Where $q_0 = 1$, it can be seen from Eq. (1) that the system function $F(\mathrm{x})$ can be completely determined by its denominator polynomial coefficient. Since $F(\mathrm{x})$ is a stationary filter, its denominator polynomial must have a minimum phase. The relationship between a minimum phase filter group delay function and its complex cepstrum coefficients is as follows:

$$\alpha(w) = \sum_{i=0}^{\infty} p\beta(p)\cos(pw) \tag{2}$$

The complex cepstrum sequence $\beta(p)$ must be a real causal sequence. According to the symmetry property of the Fourier transform, the inverse Fourier transform is obtained for Eq. (2):

$$\begin{aligned} \mathrm{IDFT}(\alpha(w)) &= \tfrac{1}{N}\sum_{j=0}^{N-1}\sum_{i=0}^{\infty} p\beta(p)\cos(pw)Q_N^{-j\mathrm{n}} \\ &= \tfrac{n\beta(n)}{2} \end{aligned} \tag{3}$$

Equation (3) shows that in the case of a known filter group delay function, the cepstrum sequence corresponding to the filter can be found. According to the basic theory of complex cepstrum, the minimum phase sequence and its complex cepstrum coefficients are satisfied:

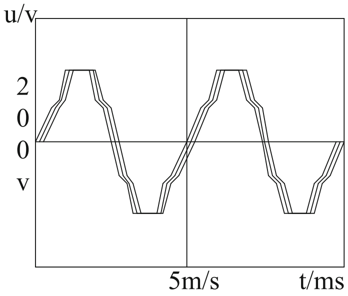
$$\mathrm{s}(p) = \sum_{i=0}^{p} \binom{p}{n} \beta(n-p), n > 0 \tag{4}$$

Where $\mathrm{s}(0) = 1$. The parent polynomial coefficient can be scored by Eq. (4). Its main steps are:

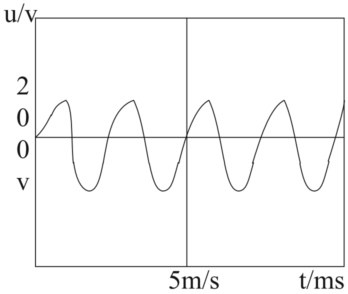
> First, the group delay function of the denominator sequence is calculated according to the specified all-pass filter group delay function;
> Secondly, the cepstrum coefficient of the denominator sequence is obtained by the denominator group delay function;
> Finally, the coefficients of the scoring parent polynomial are obtained from the cepstral coefficients, and the system function of the filter is determined.

4 Simulation

In order to verify whether the above design method is reasonable, the filter design experiment was completed in the 380 V/2.2 kW cage asynchronous motor speed control system driven by the three-level inverter developed in the laboratory. The result is shown in Fig. 6.



（a）Inverter output voltage waveform without filter rated load



（b）Inverter output voltage waveform after filtered rated load

Fig. 6. Experimental waveform

Figure 6(a) shows the output voltage and current waveform of the inverter when the rated load of the all-pass filter for power communication with high anti-harmonic interference is high; Fig. 6(b) shows the output voltage and current waveform of the inverter when the rated load is filtered.

According to the above content, the output voltage and current harmonic content of the all-pass filter system of the conventional system and the high-anti-harmonic interference power communication are compared and analyzed. The results are shown in Table 1.

Table 1. Two system output voltage and current harmonic content

	Traditional system	All pass filter system	Actual value
Near maximum voltage harmonic content/%	10.1	2.2	2.1
The maximum current harmonic content in the vicinity/%	0.32	6.65	6.60
Total harmonic distortion/%	23.5	5.4	5.5

According to the comparison results of Table 1, it can be seen that the output voltage and current harmonic content of the all-pass filter system is a high-anti-harmonic power communication system. The total harmonic distortion is much smaller than that of the traditional system, and the obtained results are basically consistent with the actual values, indicating that the system design is reasonable.

5 Conclusions

The higher harmonic problem is the medium-voltage high-power multi-level variable frequency drive device inherent in the all-pass filter system for power communication of harmonic interference. The reasonable design of the filter can reduce the insulation requirement of the motor and improve relative to the carrier frequency and increasing the number of output voltage levels to reduce higher harmonics are simpler and more economical. The experimental results show that the filter output voltage and current harmonic content of the system design are basically consistent with the actual values, and can be widely used in power communication systems.

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