Research on Test System of Signal Interference Resistance of Power Communication Carrier Channel

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Abstract. In view of the current low-reliability and low accuracy of power line carrier communication performance test equipment in the anti-interference performance test, the article deeply analyzes the technical implementation of the test system and the key technology requirements of anti-interference test. The electromagnetic conduction and radiated crosstalk and its multipath interference existing in the test system frame structure are studied, and the communication performance test system of the point-to-point carrier communication module is designed in the low-voltage power line channel environment. The test system has a simple structure and strong practicability. It can realize point-to-point communication error rate test and effective communication rate test, and can comprehensively evaluate the performance of the communication module according to the test result, and can horizontally compare the communication performance of the carrier communication modules of different manufacturers. The communication performance of different types of carrier communication units of the same manufacturer can be compared vertically, and the versatility is strong.

1. Introduction

The low-voltage distribution line conforming to the power frequency energy transmission has completely different states for carrier communication, because the carrier communication frequency is higher (mainly concentrated in 9 to 500 kHz), the line itself becomes larger as the frequency increases, and the user uses electricity. The electrical device exhibits an impedance characteristic different from the power frequency at a high carrier frequency, and the topology of the line aggravates the diversity absorption of the carrier frequency band; there are also a large number of various types of noise on the line, which are not only introduced by the user with the work of the electric appliance. Conducted noise, as well as radiated noise from the outside, the spectral components of its interference cover almost all carrier communication bands. All of these phenomena have a great impact on carrier communication, shortening the actual transmission distance of carrier communication.

Communication distance mainly depends on two key factors, one is peer-to-peer communication capability, and the other is routing networking technology. The latter focuses more on software functions
such as communication rates, adaptive algorithms, and relay routing. The low-voltage power line carrier point-to-point communication performance is mainly manifested in the following aspects in addition to the communication rate: signal transmission level, receiving sensitivity, anti-interference ability and impedance adaptability. Establish a set of low-voltage power line carrier point-to-point communication performance test platform that can quantitatively test the above parameters, not only can vertically compare the peer-to-peer communication capability of the carrier communication unit, but also horizontally compare the carrier communication units of different types of different manufacturers in the same environment [1]. The point-to-point communication performance provides a technical basis for the comparison, improvement and design of the power line carrier communication unit. In this paper, the anti-jamming test project: the demodulation threshold SNR and the receiver sensitivity test requirements, proposes solutions and modifications, based on high-performance EMI filters, shielding boxes, coaxial programmable attenuators and other key components, established a more Test environment and test system for perfect carrier communication.

2. Carrier communication anti-interference test key technology requirements

2.1. Carrier Communication Test Technology Principles

For many different low-voltage distribution network power line carrier communication schemes, the basic design idea of the existing test system is to follow the test items and test methods formulated by the national network inspection standard specification, simulate the characteristics of the low-voltage distribution network power line transmission channel, and take the measurement and control computer as The control center establishes an automated power line carrier communication performance test procedure. The test environment implementation mechanism can be briefly described as: three-phase AC purification power supply, AC power isolation device and artificial power network to effectively isolate the overall test environment from the mains network; the control center intelligently controls noise, attenuation, impedance and load characteristics, and completes the protocol. Data transmission control and analysis are conducted to achieve effective simulation and communication performance verification of the power line carrier communication environment.

![Figure 1. Carrier communication performance test system structure](image)

Different from the common power line channel of the low-voltage distribution network power information collection site, the power frequency AC power path and the power line carrier channel of the test system are relatively separated and independent. From the principle point of view, the purpose
is to prevent the carrier signal from passing through the attenuation network and the impedance network. The channel other than the one arrives at the receiving end [2]. The existing power line carrier communication performance verification equipment basically belongs to this architecture (see Figure 1).

2.2. Anti-interference test project and its key technical requirements

The transmission characteristics of the low-voltage power line carrier channel are determined: carrier signal attenuation and noise interference of the power line. The success rate of carrier communication mainly depends on the signal-to-noise ratio requirement and receiving sensitivity of the received carrier signal [3]. In the laboratory environment, the AC channel and the carrier channel do not require a high degree of isolation in the strict sense of the standard, except for the test items and test methods of the standard specification, because these test items and their specifications require such as carrier signal frequency and frequency band, maximum output level and Out-of-band disturbance levels, including transmission success tests [4-6], are basically functional and compatibility tests and do not require very precise and controllable channel attenuation as a necessary test.

At present, two types of test items, demodulation threshold SNR and reception sensitivity (lowest reception threshold), can be used to evaluate the anti-interference performance of the carrier communication system. However, effective testing of these projects requires the establishment of a relatively accurate and controllable channel attenuation in an actual test environment rather than just a principle independent carrier channel. Therefore, in the complex electromagnetic conduction and radiated crosstalk environment, how to establish a highly isolated and independent AC channel and carrier channel for multipath interference is a key technical requirement for anti-interference performance testing.

3. Anti-interference test accuracy and reliability study

The so-called test accuracy refers to the closeness of the test result to the true value of the carrier communication device, and its emphasis on the degree value; the so-called test reliability here is not the fault-free operation of the test system itself, mainly refers to the reliability of the test result.

3.1. Interference model establishment

The white noise source is filtered and generated. The transfer function \( H_{\text{mod}}(z) \) of the noise shaping filter on the plane can be described as:

\[
H_{\text{mod}}(z) = \frac{B(z)}{A(z)} = \frac{1 + \sum_{i=1}^{m} b_i z^{-i}}{1 + \sum_{i=1}^{n} a_i z^{-i}} \tag{1}
\]

Among them, \( B(z) \) represents the moving average (MA) part, and its denominator \( A(z) \) represents the autoregressive (AR) part. The model parameters consist of the variance \( \sigma_z^2 \) of the noise source and the filter coefficients. By using the AR processing model, namely: \( B(z) = 1 \), the parameters can be determined from the noise signal measured with the AR spectrum analyzer.

The superposition of \( N \) independent sinusoidal functions yields the following formula:

\[
n_{\text{narrow}}(t) = \sum_{i=1}^{N} A_i(t) \sin \left( 2\pi f_i t + \varphi_i \right) \tag{2}
\]

\( f_i \) is described by amplitude \( A_i(t) \) and phase \( \varphi_i \). The amplitude \( A_i(t) \) can be either a constant in time or a modulation amplitude that is better approximated for the AM broadcast signal. The carrier
phase can be selected with a random number in interval $[0, 2\pi]$ and is independent of time. Noise can be synthesized either in the time domain or in the frequency domain and then by inverse fast Fourier transform (IFFT).

The impulse noise frequency is 10dB, sometimes more than 40dB, the pulse intensity is related to the intensity of the noise source and the distance of the noise source from the receiving device; the pulse frequency of the main pulse series is generally 120Hz, which is synchronized with the positive and negative periods of the 60Hz power supply voltage; 120Hz impulse noise, whose pulse width changes by several percentage points; the pulse width is related to the selected amplitude level $T$. Generally, the pulse width decreases with increasing $T$ [7]; some noise sources will increase the background noise power, others will increase the impulse noise power.

The probability of $t_w$ is expressed as discrete time $k$ as:

$$P_w(k) = \sum_{j=1}^{w} g_{w+1,j} \cdot g_k^k \quad (k = 1, 2, \ldots)$$

$g_{w+1,j}$ represents the transition probability when a certain state $j$ in B transitions to the critical state $w+1$ (the pulse starts to disappear), and $g_k^k$ represents the probability that the state transition (pulse hold) does not occur in a certain state in B.

The probability of $t_A$ is expressed as discrete time $k$ as:

$$P_A(k) = \sum_{j=1}^{k} u_{v+1,j} \cdot u_k^k \quad (k = 1, 2, \ldots)$$

$u_{v+1,j}$ represents the probability of transition from a state $j$ in A to a critical state $v+1$ (a pulse starts to occur), and $u_k^k$ represents a probability that a state transition (no pulse hold) occurs in a certain state in A.

### 3.2. Signal radiated and conductive coupling of the test system

#### 3.2.1. Radiation coupling between carrier transceivers.

The radiated emissions of untargeted antennas (wires, printed circuit board traces, and metal components) in the system are important for equipment and system level EMC performance [6]. The carrier communication unit is actually a radio frequency data transmission station, the carrier coupler is a radio frequency transceiver duplexer, and the low voltage power line is a low efficiency transceiver antenna (see Fig. 2). The current narrowband carrier communication unit has a transmission level up to 10 V peak-to-peak and is converted to a 50-ohm impedance line with a peak power of 500mW, which is 10 times the 50mW emission limit of the micro-power radio station. The laboratory carrier communication test system, the device under test and the test device are mutually transcribing devices. As a digital transmission station deployed in close proximity, the same-frequency wireless radiation link will form another carrier channel, which will affect the stability, accuracy and reliability of the anti-interference performance test results [8].
3.2.2. Power line component conduction and radiated crosstalk. In the carrier test system, the components such as power line attenuation and isolation network are in an impedance mismatch state, thereby generating reflections to form standing waves, causing signal ringing and radiated crosstalk. Taking the EMI power filter as an example, the working mechanism is to establish a mismatch connection of the port impedance, strong reflection on the high frequency differential mode and common mode interference, and the insertion loss inherent in the filter network to form a more effective suppression of the EMI signal. Therefore, the reflection oscillation, standing wave, conduction and radiation coupling of the carrier signal in the test system are inevitably strong. When the carrier signal is transmitted through the power line conductor, crosstalk is formed on the adjacent conductor by capacitive coupling and inductive coupling. The carrier test system includes a large number of relay components and components such as power supply filtering, carrier coupling, and attenuation network. The power line has a complicated entry and exit relationship. When the space of the cabinet is limited, it is difficult to effectively isolate the incoming and outgoing cables. At the same time, it is considered that the wiring of the equipment is neat and orderly, and the cables are often bundled in parallel, and the conduction coupling between the lines is unavoidable.

3.3. Accuracy Analysis of Power Thread Controlled Attenuation Network
The power-threaded attenuator is a standard LC filter in the industry. It consists of a safety capacitor and a word-inductor plus an input-output electromagnetic holding relay. Due to the error level and nominal value of commercial components, and the influence of layout and layout of printed circuit boards, the measured values and design values of LC attenuators often have large deviations. The multiple tests are not consistent, accuracy and stability. Poor.

For the attenuation test of each carrier communication product, a four-stage low-range (10dB, 20dB, 40dB, 60dB) attenuation unit is cascaded to form an attenuation network with high attenuation; multiple attenuation networks are connected in parallel to form an attenuation array, Respond to a large number of manufacturers and a variety of products. In practical applications, most of the provinces have been required to provide attenuation channels that satisfy more than six products, thus constructing a 7x4 attenuation matrix structure (see Figure 3). Complex LC network and compact parallel power cables lead to uncertain and unstable network attenuation range. Multiple power-on test starts, the attenuation values are different, and it is difficult to find out the rules. It is difficult to effectively implement anti-interference test. Project.
4. Test system improvement plan and test case

4.1. Test System Improvement Plan
The power line acts as a carrier communication medium. Unlike the usual RF coaxial channel, it carries two types of signal transmission, one is a power frequency strong electric signal, and the other is a carrier (radio frequency) weak current signal. Based on the foregoing analysis, the main reason for influencing the anti-interference performance test is that the test system has strong electromagnetic radiation and conducted crosstalk, resulting in multipath transmission effect of the carrier signal, and cannot form an effectively isolated carrier channel.

The improvement plan has taken the following improvements:

(1) Add a shielding box to the carrier communication transceiver equipment, ground well, and establish an electromagnetic shielding environment between the carrier RF transceiver units;

(2) Pay attention to the selection and installation of EMI power filter. Firstly, the filter network structure is selected according to the principle of impedance mismatch. Secondly, the metal shell of the power filter is tightly contacted with the chassis and grounded well. Thirdly, the twisted pair is selected as the filter. Input and output connection lines, and open the distance to avoid parallel wiring, and finally achieve effective isolation of the power line carrier signal, establishing a practical independent AC path;

(3) Improved design of the attenuation network, replacing the complex LC attenuation matrix with the mature 50 Ω coaxial programmable attenuator in the RF communication industry. The attenuator frequency range is DC ~ 3GHz, the attenuation range is 127 dB, and the step is 1dB, which effectively improves the system test accuracy and reliability;

(4) Optimize the layout and layout of the rack, increase the chassis appropriately, open the cable distance, and reduce the parallel wiring;

The key components of the system are EMI filters, carrier separation couplers and electromagnetic shielding boxes. The split coupler isolates the power frequency strong electric signal to couple the high frequency carrier signal; the EMI power filter is just the opposite, effectively filtering the carrier signal to couple the power frequency signal (see Figure 4).
At present, power line carrier coupling technology is relatively mature, simple and effective. The industry's ultra-high-performance EMI filter has a common mode interference rejection capability of 50 dB to 80 dB in the frequency range of 70 KHz to 20MHz. In addition, the filtering capability of the artificial power network can effectively isolate the carrier signal.

4.2. Anti-interference performance test methods and test examples

Determining the signal-to-noise ratio of the demodulation threshold at the digital transmission rate is defined as the minimum signal-to-noise ratio at 50% success rate for white noise and single-band narrowband noise. Test method: first record the communication rate; then add 100dBμV white noise or 120dBμV carrier center frequency single-frequency point narrowband noise at the noise input, measure the noise level at test port 2; in the third step, adjust the programmable attenuator until the receiving end has a steady state 50% success rate, and the command is sent no less than 100 times. In the fourth step, the noise source is turned off, the signal level is measured at the measurement port 2 and recorded; finally, the signal to noise ratio S/N is calculated. The receiving sensitivity test method is similar, just turn off the noise source. Based on the improved test system, the measured data of the two carrier products are shown in Table 1.

| Data rate | White noise demodulation threshold | Receiving sensitivity | Equipment type |
|-----------|-----------------------------------|-----------------------|----------------|
| 800bps    | 5 dB                               | 13dBuV                | Carrier frequency 390kHz OFDM modulation |
| 2.4kbps   | 7 dB                               | 15dBuV                |                |
| 8 kbps    | 9 dB                               | 18dBuV                |                |
| 350 bps   | 1 dB                               | 33dBuV                | Carrier frequency 132kHz BPSK modulation |
| 1.37 kbps | 4 dB                               | 34dBuV                |                |
| 5.5 kbps  | 10 dB                              | 35dBuV                |                |

5. Conclusion

The power line channel is the same open wireless channel. Electromagnetic radiation is one of the key factors limiting the promotion of power line carrier communication. For the carrier test system, strong electromagnetic radiation and conduction crosstalk affect the stability and accuracy of the anti-interference performance test. The proposed scheme is applicable to both point-to-point power line
carrier communication performance test, and is also applicable to large-scale carrier communication network route performance test system.

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