Research and Analysis of the Influence of Power Carrier Communication on Smart Meter

Xi Li*, Shubei Hua, Jiangfeng Sun
Marketing Service Center of Qinghai Electric Power Corporation, China

*Corresponding author email: xi_li@qh.sgcc.com.cn

Abstract. Analyze and study the impact of power carrier communication on smart energy meters, and analyze the measurement function, timing function, storage function and carrier communication function of smart energy meters through various bandwidth, frequency and intensity of carrier communication impact tests. Whether the various functions are affected, and provide data support for the in-depth study of the energy meter detection method and operating environment.

1. Introduction
With the continuous development of smart grids in China, users’ requirements for smart grids continue to increase. The remote meter reading system in the smart grid can liberate a lot of manpower, save costs, and greatly improve the level of intelligence and automation of the grid. Among the various implementations of remote meter reading, the low-voltage power line carrier communication technology shows unique advantages. Its transmission medium is the existing power line network. The carrier signal is superimposed on the power line to transmit data, which allows the communication network to cover every corner, the existing low-voltage distribution network is fully utilized, saving the cost of channel laying.

At present, the smart energy meter with carrier communication function has been vigorously promoted by the State Grid Corporation, but the relevant technical standards only qualitatively stipulate that the smart energy meter can be accurately measured under the carrier communication state, and does not affect the data stored in the meter. The specific experimental method and reasonable error range of the influence of carrier communication on the measurement error of smart electric energy meters are not explicitly proposed. Therefore, the influence of the power carrier communication on the smart energy meter is analyzed and studied, so that the smart energy meter can normally and stably perform trade settlement work, ensure the interests of both power users and power companies, and achieve higher economic value benefits.

2. Modeling and analysis of power carrier signal
The performance evaluation of the low-voltage power line carrier communication system must be implemented through a reasonable channel model, which should be able to simulate the channel frequency domain response and noise waveform in different environments. In the field of communication, some generally accepted channel models are usually used, and for low-voltage power line communication systems, the MK model is currently mainly used to evaluate the signal performance of the carrier system. However, the model is mainly based on the static characteristics of
the channel, and does not take into account the power frequency period characteristics of the channel in the power grid environment, and studies the low-voltage power line noise and channel modeling methods.

2.1. Power line noise model
Due to the wide variety of noise sources in low-voltage power grids, in order to better reflect the time-domain characteristics of power line noise, it can be divided into stationary random noise and random impulse noise according to its statistical characteristics in the modeling process.

1) Stationary random noise model
The stationary random noise is mainly composed of background noise and narrow-band noise. The amplitude of the power spectrum decreases with increasing frequency and the power harmonic density is low. The statistical characteristics of the time and frequency domains remain relatively stable and have a stable random characteristic. The stationary random noise can be synthesized by filtering from the white noise source. The transfer function of the noise shaping filter is as formula 1. When the numerator is 1, the function is transformed into the expression of the autoregressive model.

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

The background noise is established based on the results of long-term measurements of the noise domain and time domain in different environments. Model parameters include white noise variance and filter coefficients, and specific values can be obtained by solving equations using Levinson-Durbin recursive algorithm. Because the power harmonic density changes slowly over time, the parameters need to be modified only when the noise environment changes significantly. The advantage of this model is that it has fewer coefficients and high calculation efficiency, and the model has better approximation when it has a high order.

2) Random impulse noise model
Random impulse noise is composed of a series of continuous pulses on the time axis, which can be equivalent to the superposition of multiple single pulses. The pulse model formula is as follows. Each pulse waveform is formed by superimposing multiple attenuation sine waves.

\[
N = \sum_{n=0}^{m_{\text{max}} T_a} A \sin(\omega(t - n t_a)) \exp(-\alpha(t - n t_a))
\]  

In the formula, \( a \) stands for pulse amplitude, \( t_{\text{arr}} \) stands for pulse interval, \( t_w \) stands for pulse width, and \( \alpha \) stands for attenuation rate. The analysis of the interference characteristics of a specific load can be achieved by playing back the recorded data with a high sampling rate.

2.2. Power line channel model
Due to the resonance characteristics of the power line line and the load impedance, the frequency selective fading of the channel is caused. At the same time, the length of the transmission line and the number of branches also cause the channel transmission loss. Based on the transmission line theory, the power line channel model is established.

1) Line model
The transmission line can be regarded as a two-port network, and its behavior can be described by a transmission matrix. The parameters of the matrix can also be called ABCD parameters. ABCD parameters allow several consecutive two-port networks to be connected in series, and global parameters are obtained through parameter calculations. According to the general method of
expressing 2PN in transmission line theory, the transmission matrix is used. The 2PN model of the cable is a reciprocal two-port network. The cable is a symmetric channel, that is, driving from either end will get the same value.

(2) Network structure
In the modeling and analysis of power line communication channels, the influence of complex network structures on channel transmission characteristics must be considered. A typical low-voltage distribution network connecting the trunk and branch lines is called a power distribution cabinet. The branch lines are directly connected to the shunt plugs, and the shunt plugs are then connected to various outlets in the room through internal lines. The power distribution cabinet and the shunt plug generally use a star connection, and the connection method of the shunt plug and the socket in the room can be divided into a star type and a bus type.

(3) Load model
In the process of power line channel modeling, it is very important to reasonably describe the impedance characteristics of the load model. The impedance characteristics of the load are various and will change with the working state of the load. When electrical equipment is connected to the line, it will affect the characteristics of the channel in two ways. On the one hand, it affects the input impedance of the channel, making the impedance of the receiving end unmatched and causing signal reflection, which causes channel multipath fading; on the other hand, the nonlinear characteristics of the device cause the resonance characteristics of the load, so that the load impedance exhibits frequency selection characteristics Affect the input impedance of the receiving end.

3. The establishment of power meter test system for electric energy meter
In order to verify the impact of the energy meter carrier communication on the energy meter measurement error, the test plan as shown above is built. According to the system diagram, the entire system includes a standard power source, carrier attenuator, carrier concentrator, carrier energy meter, standard clock tester, and reading the software is composed of several parts. The block diagram of the power carrier test system is shown in Figure 1.

![Figure 1. Block diagram of power carrier test system.](image)

The standard power source mainly provides standard energy signals for the system and the energy meter to be tested, and compares the errors. The carrier attenuator mainly isolates the high-frequency carrier signal of the energy meter and the carrier concentrator from the power source to avoid the influence of the carrier signal on the standard meter. The carrier concentrator mainly reads the energy meter and simulates the on-site reading environment with the carrier energy meter. The carrier energy meter is used as the meter meter of the subsequent stage and as the measured energy meter. The clock tester is mainly used as the standard for the time error of the energy meter. Copying software is mainly used to detect the RS485 and internal storage of various functions of the energy meter.

An attenuator is a circuit used to introduce a predetermined attenuation within a specified frequency range. It is generally indicated by the decibel number of the attenuation introduced and the ohm number of its characteristic impedance. Attenuators are widely used in cable television systems to
meet the level requirements of multiple ports. Such as the control of the input and output levels of the amplifier, and the control of the amount of branch attenuation. There are two types of attenuators: passive attenuator and active attenuator. The active attenuator is combined with other thermistors to form a variable attenuator, which is used in the automatic gain or slope control circuit in the amplifier. Passive attenuators have fixed attenuators and adjustable attenuators. The carrier attenuator design is shown in Figure 2.

![Carrier attenuator design scheme diagram.](image)

The power line carrier signal adjustable attenuator is an important device for testing power line carrier communication equipment. Based on the power line carrier signal adjustable attenuator, it can detect the performance parameters such as the transmission intensity, transmission efficiency, and reception sensitivity of the carrier communication device. The ability to interfere can also be used to achieve a controllable network relay relationship in the networking test. The attenuation value of the existing power line carrier signal circuit needs to be improved. The attenuation value can be adjusted through the component value. It is designed to be 2-127dB adjustable and the communication method is RS485 or 232.

### 4. Test and Analysis of the Narrowband Carrier Communication's Influence on the Energy Meter Function

Remove the carrier module, build an energy meter carrier test environment, make the energy meter work in a normal state, test the energy meter error, and draw the error curve, as shown in Figure 3. Add the carrier module to the electricity meter, measure the energy meter error, and draw the error curve, as shown in Figure 4.

![Narrowband carrier energy meter measurement error curve (without carrier module).](image)
Figure 4. Narrowband carrier energy meter measurement error curve (with carrier module).

The influence of the carrier on the timing error is to remove the carrier module, measure the daily timing error, and draw the error curve, as shown in Figure 5. Add the carrier module to the electricity meter, measure the timing error of the day, and draw the error curve, as shown in Figure 6.

Figure 5. Narrow-band carrier energy meter timing error curve (without carrier module).

Figure 6. Narrow-band carrier energy meter timing error curve (with carrier module).

The narrowband module uses FSK technology for analog signals, and only a single signal is transmitted at the same time; while the wideband module uses OFDM technology to transmit multiple frequency signals at the same time. The narrow-band carrier has little change to the energy meter error, and has no effect on the energy meter storage information and daily timing error.

5. Conclusion
In this paper, the channel characteristics of low-voltage power line carrier communication are measured and analyzed. A channel model suitable for power line carrier communication simulation is
established. The simulation of the time-varying characteristics of the channel that cannot be solved by the static model is implemented. The research provided reference basis and tools.

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