Research on Smart Grid Power Line Broadband Communication System

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Abstract. With the rapid development of high-speed carrier communication technology, high-speed carrier communication technology has become a new choice for power information acquisition systems. High-speed carrier communication technology achieves excellent application results in the construction of power information acquisition system by virtue of its high communication rate, high real-time communication, support for automatic networking and real-time routing, support for phase identification and station identification. Therefore, the power line carrier communication technology in the smart grid has become more and more important. This paper introduces the key technologies of power line broadband carrier communication in detail, analyzes and studies the design difficulties, and studies the smart grid power line broadband communication system through practical application. It provides powerful technical support for smart grid power line broadband communication.

1. Introduction
Power line carrier communication technology has been widely used in various occasions of foreign electricity information collection or advanced metering systems, and has been widely used in the field of automatic meter reading in China. In addition to power information collection, power line carrier communication technology can also be widely used in smart home, building control and Internet of Things. At present, power line carrier communication technology is developing from narrowband to broadband. Broadband carrier communication has become a hotspot technology for research and development and application of power line carrier communication in recent years. At present, China Power Grid Corporation and State Grid Corporation of China Southern Power Grid Corporation are developing or have formulated The broadband carrier communication data transmission protocol of the electric information acquisition system can foresee the broad and important application prospect of the broadband power line communication technology [1].

In the development of broadband carrier communication data transmission protocol and the development of broadband carrier communication technology, it is necessary to simultaneously study broadband carrier communication conformance testing technology and system. Through conformance testing, it is possible to verify whether an implementation of the protocol is consistent with the protocol specification that it complies with, and it is also the basis for ensuring that communication devices developed by different device vendors can be interconnected. Therefore, the development of
the broadband carrier communication protocol conformance test system is of great significance for promoting the standardization of broadband carrier communication and device interconnection.

The smart grid power line broadband communication system designed in this paper uses the separation of power frequency and carrier communication signals to quantitatively and qualitatively analyze the quality and routing capability of broadband carrier communication signals. The test results are stable, reliable and repeatable; Standard requirements for high quality communications in smart grids.

2. Main implementation technology

2.1. Broadband carrier communication protocol

The broadband carrier communication data transmission protocol specifies the physical layer, data link layer and application layer technology of the broadband carrier communication network for the power user information collection system, and the concentrator communication unit and the energy meter applicable to the electricity information collection system. Data exchange mechanism between communication unit and collector communication unit. In the power line communication network composed of a wideband carrier system, three device roles are defined: a central coordinator (CCO), a proxy coordinator (PCO), and a station (STA). The CCO is the master node in the network and is responsible for completing the functions of networking control, network maintenance management, and power consumption information collection. The corresponding device entity is the concentrator local communication unit; the PCO and STA are corresponding to the power meter and collector. A communication unit device, wherein the STA is a slave node in the network, and the PCO connects the CCO and the STA as a relay node in the network.

In the networking process, the broadband power line communication network generally forms a multi-level tree network with CCO as the center and PCO as the relay agent to connect all STAs. As shown in Figure 1, the typical broadband power line communication network topology is shown.

![Figure 1. Broadband Power Line Communication Network Topology](image)

The protocol stack of the broadband power line communication network is as shown in FIG. 2, and includes a physical layer, a data link layer, a network layer, a transport layer, and an application layer. Generally, in a broadband power line networking environment, the network layer and the transport layer can be omitted.

The application layer implements service data interaction between communication units, and completes data transmission through the data link layer and the physical layer. The data link layer is divided into a network management sublayer and a medium access control (MAC) sublayer, and the network management sublayer implements a broadband power line communication network; the MAC
sublayer accesses the physical channel through two channel access mechanisms: CSMA/CA and TDMA. To achieve reliable transmission of messages. The main functions of the physical layer are to perform transcoding and modulation at the transmitting end, as well as demodulation and decoding at the receiving end.

![Application layer diagram]

**Figure 2.** Broadband Power Line Communication Network Protocol Stack

### 2.2 Broadband Power Line Carrier Technology Based on Intelligent Network Protocol

Broadband power line carrier technology utilizes a technique in which a carrier signal is loaded into a low-band (usually below 30 MHz) modem to implement multi-carrier compliance techniques for information transfer and data acquisition. Intelligent network protocol is a solution proposed by the intelligent network alliance for the demand of smart grid [2]. This scheme has good economic advantages. The intelligent network protocol is compatible with Homeplug AV. In use, the intelligent network protocol The working frequency band is between 2~30 MHz, and 1 255 subcarriers only use WPSK modulation. Each wavelet interval is 25.232 kHz. The data transmission uses the effective error correction mechanism. The intelligent network protocol uses the modulation method in the communication protocol. And the way data is transmitted, the signal transmission power can be minimized in the maximum criterion. Minimize the consumption of carrier units.

The intelligent network protocol can be used in the power line carrier system to solve the shortcomings such as fast communication loss, poor self-healing capability and poor timeliness. The existing carrier set-copy system in our country is a narrow-wave product. Due to the large geographical differences in our country, the development of the carrier aggregation system in each region is different, which results in a big difference in the operation results. The narrowband carriers used in our country are shown in Table 1.

| Table 1. Narrowband carrier parameters |
|----------------------------------------|
| Carrier type | Narrowband carrier | Wideband carrier |
|--------------|--------------------|------------------|
| Carrier rate | 330/1000/1500 b/s  | 4/5/10 Mb/s      |
| Carrier center frequency | 131.5/270.37 kHz | 2~30 MHz         |
| Modulation   | BFSK/DBPSK         | OFDM             |
| Maximum number of networking stages | 7                  | 16               |
It can be seen from Table 1 that the maximum communication speed of the narrowband carrier product is only 1/6 600 of the maximum communication speed of the broadband carrier product, and can only be used for ordinary when the carrier speed is 330/1 000/1 500 b/s. The use of the table, the interaction is relatively poor, can not meet the power customers for business needs, if you use the intelligent network protocol, you can solve this problem in time.

2.3 Carrier Signal Isolation and Radiation Shielding

The carrier signal is transmitted by power line, and cannot be directly connected to a precision instrument for measurement [3]. The power frequency signal and the power line carrier signal need to be separated by signal coupling sampling. The carrier signal is transmitted in the 2~30 MHz frequency band, and the modulation mode is OFDM [4]. When the distance is relatively close, the wave power of the download wave is large, and crosstalk is not detected under the condition of no shielding and isolation, and the measurement cannot be accurately performed. Under the condition of free networking of carrier nodes, the network topology is time-varying and uncontrollable. In order to accurately evaluate carrier communication routing and transceiver performance, pure power line isolation and wireless shielding environment are required, and each node is completely isolated and does not interfere with each other. The isolated shielding device designed in this paper uses a low-frequency shielding box and a power line filter. The box body introduces 220 V high-voltage to solve the problem of wide-band carrier zero-crossing detection, and can also isolate carrier signal crosstalk and airborne radiation on the external power line [5] signal.

2.4 Switch matrix

In the performance test, the signal analyzer needs to be connected to analyze the occupied bandwidth and power spectral density of the carrier communication signal. In the anti-attenuation performance test [6], the attenuation between the master node CCO and the child node STA is required, and the anti-frequency offset test is performed. The reference clock offset of the medium transparent transceiver unit requires the use of a high precision clock provided by the signal source. At the same time, the communication network test requires the master node CCO access signal matrix and the 15-level child node STA communication. It is necessary to connect each part into a communication link, and realize the switching of the signal source in the noise test and the frequency offset test through the radio frequency control switch [7]. Due to the large number of devices connected, it is inevitable to introduce a brancher. The loss of the branch can be accurately measured by a vector network analyzer. The broadband carrier signal can be accurately tested by coupling insertion loss and branch loss compensation.

When the input power of the system is large, the loss of the switching matrix will increase. It is assumed that the two single frequency signals are all A, and the frequency is w1 and w2.

\[ V_i(t) = A(\cos w_1 t + \cos w_2 t) \]  

(1)

The linear output component of the switch matrix is as follows:

\[ a_1 (A \cos w_1 t + A \cos w_2 t) \]  

(2)

The secondary component is:

\[ a_2 A^2 [1 + \frac{\cos 2w_1 t + \cos 2w_2 t}{2} + \cos(w_1 - w_2) t + \cos(w_1 + w_2) t] \]  

(3)

Formula (3) can be obtained that the third-order cross component is:

\[ \frac{3a_3 A^3}{4}[\cos(2w_1 - w_2) t + \cos(2w_1 - w_2) t] \]  

(4)

By the formula (4) it can be seen that when the matrix power input rf signal for 25 dBm signal output size of 0 dBm, smaller than the output of the matrix P - 1 10 dB, the third order at this time in the component is smaller than the linear component about 60 dB. In general, in order to meet the dynamic range of the system without clutter and the system residual, the output power of signals passing through all levels of active devices should return 2~3 dB on the basis of the device's p-1.
3. Overall design
The broadband carrier test system consists of three parts: the performance test subsystem, the protocol
test subsystem, and the interoperability test subsystem. Among them, the performance test subsystem
mainly tests the broadband carrier communication unit physical layer transmitter performance,
receiver performance, frequency offset performance, anti-attenuation performance, anti-noise
performance and communication rate, etc., by the primary node carrier communication unit (Central
Coordinator, CCO), sub-node carrier communication unit (Station, STA), signal analyzer, signal
source, transparent transceiver device, switch matrix. The protocol test subsystem mainly tests the data
link layer and application layer protocol of broadband carrier communication, and is composed of
CCO, STA, and transparent transceiver equipment. The interoperability test subsystem is mainly
responsible for testing communication network, route relay, and multi-network coordination. It
consists of CCO, signal matrix, STA, and transparent transceiver equipment. The wideband carrier
interconnection protocol requires the carrier communication unit to support 15 levels of route relay,
and the minimum interoperability test system requires 15 child node carrier shielding units [8].
The structure of the broadband carrier test system consists of a switch matrix and a signal matrix. A
CCO/STA, a signal analyzer, a signal source, and a transparent transceiver unit are connected through
a switch matrix to form a performance test system. A CCO/STA and a transparent transceiver device
are connected through a switch matrix to form a protocol test system. The switch matrix, the signal
matrix, and the sub-node shield unit are connected through the master node shielding unit to form an
inter-operating system. The system design scheme is shown in Figure 3.

![System design scheme](image)

**Figure 3.** System design scheme

1) Transmitter performance test of the carrier communication unit. The carrier communication unit
(CCO/STA) is placed in the shielding box of the main node, and the trigger mode, starting frequency
and resolution bandwidth of the signal analyzer are set; the upper computer is connected to the test
board and the transparent transceiver unit, and the test command is issued; the signal is read. Analyzer
bandwidth, in-band power spectral density, and out-of-band power spectral density.

2) Carrier communication unit receiver performance anti-attenuation test. Place a pair of CCOs and
STAs in the shield box of the master node and the shield box of the child node, and start the
networking of the child node table address; continuously read the table and calculate the success rate;
adjust the values of the two attenuators of the switch matrix until The success rate of meter reading
reaches 90% of the specified limit. The attenuation values of the two attenuators are read, and the
intermediate path insertion loss is compensated by software to obtain the anti-attenuation values of
CCO and STA.
3) Anti-noise performance test. The CCO and STA are placed in the shielding box of the master node and the child node respectively, and the noise types are pulse noise, narrowband noise and additive white Gaussian noise respectively, and the anti-noise performance of the carrier communication unit is tested.

4) Protocol testing. The CCO/STA is placed in the main node box, and the upper computer is connected to the transparent transceiver unit. The analog STA/CCO traverses each scene and type data frame to verify whether the data link and application layer data frame format and content meet the technical specifications.

5) Communication networking and route change test. The master node CCO is placed in the shield box of the master node, the transparent transceiver unit is set to the listening mode, the child node unit is placed in the 1-15 box, the attenuation values of each level are adjusted, the relay routing table is read, and the relay is verified. Whether the level meets the 15th level; start the networking command, read the networking flag, obtain the networking completion time and the relay routing table; start the meter reading, and calculate the meter reading time and success rate.

6) Multi-network coordination and communication anti-crosstalk testing. The CCOs are placed in different boxes to simulate strong interference between CCOs, strong interference between STAs, and coordinated coexistence mechanisms between multiple networks. The carrier sense unit is activated to listen to whether each network time slot and beacon meets the requirements of the protocol specification. And whether the conflict avoidance mechanism is reasonable; start the networking and meter reading process, calculate the success rate and time of the network, and the success rate and time of meter reading.

4. Summary
This paper introduces the key technologies of power line broadband carrier communication in detail, analyzes and studies the design difficulties, and studies the smart grid power line broadband communication system through practical application to meet the specification requirements of power line broadband carrier technology. It provides powerful technical support for smart grid power line broadband communication, and has achieved good results.

5. References
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