Design of Power Consumption Tester for HPLC Power Line Carrier Communication Module

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Abstract. Due to the current situation that the power line carrier communication module power consumption test equipment has slow dynamic power consumption response and low AC power consumption test accuracy, the article deeply analyzes the key technical requirements of the communication module dynamic power consumption test, and focuses on a design of power consumption tester. The paper introduces the working principle of the tester, gives the circuit design scheme of DC power consumption and AC power consumption, and analyzes the calculation methods of static and dynamic power consumption in detail. Finally, the power consumption test results of various test systems are compared, and the test data is analyzed to conclude that the power consumption test data is stable, reliable, and high precision.

1. Introduction

With the development of the national energy strategy, power line communication (PLC) plays an increasingly important role in the construction of the smart grid. The smart grid requires that the electricity information collection system should meet automatic meter reading (AMR), load control, transformer monitoring, power quality remote measurement, security monitoring, time-of-use (TOU) rate, dynamic billing, and other various value-added services, e.g., power line telephones and Internet information services. At the same time, the State Grid put forward the goal of the construction of power consumption information collection system, i.e., the full coverage of power users, the full collection of electricity consumption information, and support for comprehensive electricity tariff control. Traditional narrowband power line communication technology can hardly meet the above requirements. The emergence of highspeed broadband power line communication technology (BPLC) improves the data transmission rate and provides assistance for the smart grid construction project and the four-meter-in-one project promoted by the State Grid[1].

So far, the State Grid and China Southern Power Grid have been bidding for more than 500 million smart meters. Due to the number of carrier modules, their power consumptions are considerable. Hence, it is very important to limit the power consumption of the carrier modules. The power consumption test of BPLC module provides one of the important indicators in the technical specification of power user information collection system. The static and dynamic power consumption of BPLC modules are both specified in the communication unit technical specification[2].
Power consumption testing of BPLC modules has two characteristics\[3\]. On the one hand, dynamic power consumption of BPLC modules changes rapidly. Taking modules from a certain manufacturer as an example, the data transmission rate is low for a narrowband PLC module, which means it will spend longer time sending the same data. For example, the time required by a module with a modulation mode of BPSK for sending an application-layer packet with a length of 16 bytes is 138 ms. However, for the BPLC module, the data transmission rate is high. The time required for sending the same data transmission time is greatly shortened to 2.97 ms. Therefore, the dynamic response of the instrument testing the BPLC module should be very high. On the other hand, high precision is required for testing the ac power consumption. The ac power loss of the PLC carrier module is only about tens of milliwatts, which is very low. So the AC test function of the power consumption meters should work in high precision.

At present, it is difficult for ordinary instruments to meet the above two characteristics. This paper designs a novel device for testing the power consumption of BPLC modules with the above two characteristics taken into account.

2. The working principle of the power consumption tester
The BPLC module power consumption tester adopts modular design, which mainly includes MCU module, power load module, DC power consumption test unit, AC power consumption module, display module and network communication module\[4\]. The DC power consumption test unit and the AC power consumption test unit are designed as two groups, respectively testing the energy meter module and the concentrator module, and the two devices to be tested are simultaneously connected to one power load module. The dynamic power consumption of the device under test can be tested by network meter reading. As shown in Figure 1, the MCU module calculates the data collected by the DC power consumption unit and the AC power consumption, and transmits the test result to the display module. The data can also be transmitted to the PC master computer software through the network communication module. The power consumption of the BPLC module consists of two parts: 12V DC power consumption and 220V AC power consumption. DC power consumption plays a major role, and AC power consumption is generally small, mainly due to the zero-crossing circuit power consumption of the module.

![Fig 1. System wiring diagram](image)

2.1 Power load module design
The power line load can affect the power consumption of the BPLC module. After the power supply is connected to the power consumption tester, the power supply must be processed first. Before the AC input to the module, the power supply should be standardized. The line impedance stabilization network can be added to eliminate the influence of the external carrier on the system and provides a stable power line load for the system test, as shown in Figure 2.

After the power supply is transformed, rectified, and filtered, it provides 12V, 5V, and 3.3V for the
entire tester. The power supply design parameters are as follows: The DC power supply design parameters: the output accuracy is better than 1%, and the voltage stability is less than 1% under different loads (output current 0~0.5A).

![Line impedance stabilization network](image1)

**Fig 2. Line impedance stabilization network**

### 2.2 DC power consumption test unit design

A general method for measuring the average DC power consumption is to sample the values of the N sets of instantaneous voltage \( u_i \) and instantaneous current \( i_i \) at equal intervals with a certain sampling rate in a certain period of time \([4]\), and then calculate the average power \( P \) according to the following formula.

\[
P = \frac{1}{N} \sum_{i=1}^{N} u_i i_i
\]

Instantaneous power consumption is the multiplication of the voltage acquisition value and the current acquisition value. Voltage sampling: The power supply voltage of the BPLC module is 12V, the measuring range of the ADC sampling chip is 3.3V, which exceeds the AD sampling voltage range. The voltage sampling uses the resistor voltage division method, respectively using 47K and 10K high-precision resistors to make the AD sampling voltage approximately 2.1V and meets the sampling requirements of the ADC chip. Current sampling: According to the relevant technical standards, the static current of the BPLC module is less than 100mA, the dynamic current is less than 500mA, and the current sampling design should reach 500mA with an accuracy of 1mA. As shown in Figure 3, the current sampling is to string the high-precision and low-resistance sampling resistor to the 12V power supply. Using a precision differential op amp, the voltage across the sampling resistor is compared and amplified to output a suitable voltage signal to Single-chip AD. The op amp uses TI's current sampling chip INA282. This chip can amplify the voltage difference across the sampling resistor by a factor of 50. It has the following features: wide common mode range -14V to 80V, offset voltage ±20uV, common mode rejection ratio 140dB, gain error(maximum) ±1.4%, and gain drift(maximum) 0.0005%/°C.

![Schematic diagram of current sampling section](image2)

**Fig 3. Schematic diagram of current sampling section**

### 2.3 AC power consumption test unit design

The AC power consumption of the general BPLC module is mainly the power consumption of the zero-crossing circuit. The calculation method is the same as that of the formula (1). The AC power consumption is calculated by voltage and current sampling. The AC voltage and current sampling unit
use a non-isolated scheme. Using the transmission data with the MCU module requires optocoupler isolation.

The AC power consumption acquisition uses the energy metering chip ESEM16 of Shanghai Eastsoft Microelectronics Co., Ltd.. ESEM16 integrates a high-precision energy metering module microcontroller, including two 24-bit ADCs for current and voltage sampling, a reference voltage source and a dedicated DSP core with active energy metering. It can meter active energy, measure voltage and current RMS, and calculate average active power. In the dynamic range of 1000:1 at 25 °C, the active energy measurement error is less than 0.1%; in the dynamic range of 500:1, the voltage and current RMS measurement error is less than 1%. The ESEM16 simulation front end consists of two programmable gain amplifiers with current amplification on one side, gains of 1, 2, 4, 8, 16, 32 times. Gains of voltage sampling are 1, 2, 4, and 8 times. After the PGA, two 24-bit AD samples are taken. The chip contains a precision reference voltage source of 1.3V to achieve high-precision voltage sampling. The AC sampling circuit is shown in Figure 4 below.

![AC power consumption test schematic diagram](image)

Fig 4. Schematic diagram of AC power consumption test

The voltage sampling adopts the high-precision resistance voltage division method. The ESEM16 voltage sampling requires the input signal to be 100μV to 500mV. According to the effective value of 220V, the design input signal is 100mV. According to the resistance voltage division, It can be calculated that R89=1K, R78=R79=R80=R81=510K. The current sampling uses a high-precision, low-resistance resistor on the power line. The ESEM16 requires a current sampling input signal of 5μV to 25mV. Then Pmin/220×R95>5μV, Pmax/220×R95<25mV. The AC power consumption of the module is mainly at the zero-crossing circuit, and the power consumption is very small. Considering the AC power consumption fluctuation of different manufacturers' modules, the AC power consumption range is set from 1mW to 300mW. According to the above calculation, the sampling resistance is 1.1R<R95<18.3R, and the sampling resistance is selected as 10R.

2.4 MCU module design

The MCU module is the core module of the power consumption tester. The MCU is selected as ST Company's STM32F207ZE. The chip has a high-speed running frequency and application interface. The ADC module has 12-bit measurement accuracy and 30MHz sampling rate, which can meet the BPLC dynamic power consumption test requirements.
2.5 Display module and network communication module design

The display module uses a touch display that allows static and dynamic power consumption testing through interface and system interaction. The network communication module can interact with the master computer software to support remote control, and can upload the test data to the PC master computer, so that the power consumption tester can be integrated into other test systems.

3. The implementation of the power consumption tester software

The power consumption tester software consists of two parts: the MCU program and the AC acquisition chip ESEM16 program. The data is interacted through the serial interface, and the serial interface line uses the optocoupler isolation. Figure 6 shows a design block diagram of the test software.

The tester software first initializes the system before sampling begins, and then the system will obtain test instructions from the display or master computer software to determine whether it is static power consumption. If it is static power consumption, it will go directly to the data acquisition and analysis processing flow. If it is dynamic power consumption test, it will enter the networking process. The networking process is similar to the actual courts application. First, the MCU module simulates the virtual energy meter and the virtual concentrator, initializes the concentrator module parameter area, and then downloads the table file and restarts the concentrator module. After that, the system will periodically query the networking status and wait for the networking to complete and enter the dynamic power consumption test process.
3.1 Data acquisition

Data acquisition mainly includes DC voltage and current acquisition and AC voltage and current acquisition. The MUC module can directly acquire DC voltage and current, and the acquired binary data can be calculated as current and voltage through the circuit voltage division formula, so that DC instantaneous power consumption can be calculated. Starting a round of sampling, each channel is acquired 100 times according to the sampling sequence, and each sequence acquires 480 Cycles, so $2 \times 10 \times 480/30000000 = 320\mu s$ is needed to complete one round of sampling. To complete sampling, there is a $1000\mu s$ delay in the program. After completing a round of sampling, the calculation takes about $3\mu s$.

The AC acquisition is done by ESEM16 and can be obtained by reading the active power register (EM_PA) value. EM_PA is a 32-bit signed number, expressed in binary complement code form, and the negative number means that the actual power direction is negative. Calculated as follows:

$$\text{PA} = \frac{\text{DATA} \times k \times V_{\text{ref}}^2}{R \times G_i \times G_u \times 2^{31}}$$

Where DATA is the decimal value of the corresponding active power register value, R is the resistance of the manganese copper shunt (in $\Omega$), k is the voltage divider ratio of the voltage channel ($k > 1$), and $G_i$ and $G_u$ are the PGA gain of current and voltage channel, $V_{\text{ref}}$ is the ADC reference voltage ($V_{\text{ref}} = 1.3\text{V}$). After the AC acquisition is completed, the test data is sent to the MCU module by monitoring the serial interface DC.

3.2 Data analysis and processing

In the static power consumption test, the system program filters each data in each sample sequence to eliminate the errors, so that the authenticity and usability of the sampled data can be ensured\cite{6}. The software program uses a limiting average filtering algorithm, which can effectively overcome the pulse interference caused by accidental factors\cite{7,8}, and significantly eliminate a large number of random noise in the power grid.

The dynamic sending time of the BPLC module is very short. The test data will include dynamic power consumption data and static power consumption data. The filtering processing of the acquired data is different from the static power consumption. The dynamic power consumption test data as shown in Figure 7, the power consumption of the module is much larger than the static power.
consumption. When processing the dynamic power consumption test data, set a threshold $P_{\text{threshold}}$. When it is larger than this threshold, it is considered as dynamic power consumption. When it is less than this threshold, it is considered as static power consumption. After acquiring multiple sets of dynamic power consumption data, the data is filtered to reduce the influence of a large amount of random noise in the power grid on the dynamic power consumption test results.

$$
\begin{align*}
    p &= \begin{cases} 
        P_{\text{dynamic}} & |p| > P_{\text{threshold}} \\
        P_{\text{static}} & |p| < P_{\text{threshold}}
    \end{cases} 
\end{align*}
$$

Because the power consumption tester has the problem of component accuracy, the test data will be offset. The power tester needs to add a power consumption compensation calibration mechanism. The power consumption compensation calibration of this solution is to add a fixed loss value $\Delta P$ to the test result.

![Dynamic power consumption test data](image)

**3.3 Data display and remote control**

The display module communicates with the MCU module through the serial interface, and can convert the display operation into serial interface command to control the power consumption tester test. Similarly, MCU module sends the test results to the display module, and the display module displays the test results.

The network communication module realizes the remote control of the power consumption tester, communicates with the PC master computer through the TCP/IP protocol. The remote communication application layer protocol is a customized protocol. The protocol has a CRC check on the data to increase the security and stability during the data transmission process.

**4. Comparison and analysis of the test results**

In order to confirm the accuracy and practicability of the power consumption tester, different test methods are used to compare the static and dynamic power consumption of the energy meter BPLC module. In order to exclude individual differences, this test selects ten energy meter modules for testing. The test results are shown in Table 1.

| Test methods                      | Static power consumption(W) | Dynamic power consumption(W) |
|----------------------------------|-----------------------------|------------------------------|
| A province metrology center      | 0.391                       | 1.351                        |
| A power meter test result        | 0.395                       | 1.034                        |
| Power consumption tester result  | 0.389                       | 1.343                        |

It can be seen from the test result data that the static power consumption test results are basically
the same under different measurement modes. But there is a certain difference when testing dynamic power consumption. The dynamic power consumption tester is consistent with the test results of a province metrology center. The test results of a power meter differ greatly from the other two methods. This is mainly because the dynamic response of a power meter is slow, and the measurement rate cannot keep up with the power consumption change when sending BPLC module.

5. Conclusion
This paper proposes a design method of BPLC power consumption tester, which is mainly composed of MCU module, power load module, DC power consumption test unit, AC power consumption module, display module and network communication module. The tester utilizes a high sampling rate ADC chip and a high-precision AC power metering chip to make DC power consumption measurement response fast and AC power consumption measurement accurate. The measurement results prove that the power consumption tester designed by this scheme is more accurate in dynamic power consumption. In addition, the design scheme is lower in cost, better in portability and integration.

Due to the technical advantages of the tester in portability, low cost and integration, especially the high dynamic response of the tester, and the high-accuracy measurement of AC power consumption, it provides a new kind of accurate measurement of BPLC module power consumption. The new method can be widely used in the power consumption measurement of various BPLC modules.

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