Design of micro intelligent current sensor

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Abstract. Smart grid and transparent power grid require extensive collection of basic information of power grid, which puts forward higher requirements for intelligent measuring technique. In this paper, the micro intelligent current sensor is developed, including the design of the whole structure of the sensor, signal processing circuit, digital processing circuit, energy acquisition, wireless communication and other functional modules, and the IP and insulation protection design is completed. Finally, the long-term trial application in the field of low-voltage power distribution is carried out. The results show that the current sensor can work stably and reliably for a long time. It has the advantages of miniaturization, high integration, convenient installation and remote management. It can collect the real-time operation data of the distribution power grid, and provide sufficient information support for the construction of the transparent power grid.

1. Introduction

Smart grid with the characteristics of wisdom, green and sustainable development is the inevitable trend of future power grid. Transparent power grid is the ultimate embodiment of the development of smart grid [1]. Transparent power grid requires extensive collection of basic information data of power grid, so that all aspects of the power system can be displayed to achieve the transparency of power information and network information, which puts forward higher requirements for intelligent sensor measuring technique.

At present, the sensing data of smart grid mainly includes current, voltage, temperature, stress, mechanical characteristics, etc. Among them, current, as the most important sensing parameter of power system, is the key to construct the "neural system" of power grid [2]. The existing current measurement methods have been difficult to meet the basic needs of comprehensive and real-time sensing information of smart grid, so it is urgent to develop a new type of intelligent sensor device [3].

In recent years, with the development of advanced sensing technology and material technology, micro intelligent current sensor has been gradually studied and applied. Among them, the current sensor based on the magnetoresistance effect has the advantages of high sensitivity, wide measurement range, good temperature stability and no AC/DC limitation [4], which is expected to be widely used. At present, the current sensor based on the magnetoresistance effect has attracted the attention of domestic researchers and carried out some research: in document [5], the high-voltage wide-band large current sensor based on the giant magnetoresistance (GMR) effect has been studied, focusing on solving the problems of high-voltage isolation and anti-interference in the strong electromagnetic environment; in document [6], the high-performance GMR current sensor for the smart grid current measurement has
been developed, and through the typical application in different power occasions such as DC converter station, seafloor DC grounding electrode stray current, the accurate measurement of the current with the bandwidth of DC to 10MHz and the amplitude of 1mA to 1.6kA is realized, which verifies that GMR current sensor can meet the measurement requirements of typical application occasions of smart grid. But at present, there is no report about the reliable operation of the magneto resistive current sensor in the distribution network for a long time.

This paper studies the current sensing technology based on the magnetoresistance effect, develops the micro current sensor with the magnetoresistance sensor as the core, formulates the self-energy supply scheme, wireless communication scheme and protection scheme, and prepares the current sensor terminal which can be used in the distribution network scene; carries out the long-term pilot application of the terminal, and verifies the stability and reliability of the terminal operation. The research and development of smart current sensor can provide more comprehensive and real-time information support for power grid operation, and then provide more comprehensive and real-time information support for rapid power system fault identification and location, networked relay protection, real-time dynamic security analysis and smart grid operation.

2. Architecture of intelligent current sensor

![Figure 1. Architecture of intelligent current sensor.](image)

The architecture of the micro intelligent current sensor developed in this paper is shown in Fig. 1, which including magnetoresistance chip, magnetic ring, signal conditioning circuit, MCU, communication module and power module. The current to be tested in the wire will generate a magnetic field in the surrounding space, and the magnetoresistance chip is affected by the magnetic field. The internal bridge resistance changes and is further converted into a voltage signal. The signal is amplified and filtered by the signal processing signal, and then converted into a digital signal by the ad module and processed and calculated by the MCU. The calculated data is uploaded by the wireless communication module to the data collection module.

3. Function module design of current sensor

3.1. Design of Magnetic Ring

Because the magnetoresistance chip is sensitive to the direction of the magnetic field, and the magnetic ring structure can ensure that the magnetic field at the air gap does not change with the deviation of the external wire, which can greatly simplify the measurement process and reduce the sensitivity of GMR chip to the current position and angle [7]. As shown in Fig. 2, perm alloy is selected as the magnetic material. The outer diameter is 44mm, the inner diameter is 34mm, the height is 10mm, and the opening gap is 5mm. The magnetoresistance chip is placed at the opening gap of the magnetic ring.
3.2. Design of Signal Conditioning Circuit

The function of the signal conditioning circuit is to amplify the two output signals of the GMR bridge structure and eliminate the common mode voltage. The signal conditioning circuit adopts an instrument amplifier structure, which can effectively resist common mode interference and have high input resistance, and effectively improve the signal-to-noise ratio. In this paper, the improved trio amplifier with monolithic integration has better matching parameters, smaller stray capacitance and inductance, smaller volume, and lower power consumption. In addition, due to the higher integration, the error of the integrated instrument amplifier due to resistance is smaller. The circuit schematic diagram is shown in Fig. 3. The circuit includes a zero drift conditioning circuit, which can adjust the output signal to zero.

3.3. Design of Signal Conditioning Circuit

The function of the MCU is to calculate and analyse the collected data, and control the wireless module to realize the remote transmission of data. In this paper, nRF52832 chip is used as the MCU chip. The chip has strong computing power and floating-point computing technology, which can meet the needs of current sensor data processing. At the same time, the chip has built-in A/D and Bluetooth transmission module, which can meet the needs of current sensor AD conversion and wireless communication. The digital processing circuit is shown in Fig. 4.
3.4. Design of communication module

3.4.1. Selection of communication. The current sensor is installed in 10kV distribution line. In order to avoid the problem of high and low voltage isolation, wireless communication mode is adopted in this paper. The design of the communication module needs to consider the transmission rate and power consumption comprehensively. According to the transmission demand, the wireless transmission rate demand of current sensor data is about 5Kbps, and the communication distance is about 10m. Therefore, Bluetooth communication with low power consumption, small volume and fast transmission rate is adopted as the wireless communication mode. NRF52832 chip has built-in low-power Bluetooth communication module, which can meet the wireless communication requirements of current sensor. The circuit diagram of communication module is shown in Fig. 4.

3.4.2. Design of communication protocol. The data processed by MCU needs to be packaged according to the customized protocol to meet the requirements of wireless communication. The protocol of the data is shown in Table 1.

Table 1. Data transmission protocol.

| Frame head | Data length | Sensor ID | Effective value of current | temperature | humidity | Voltage | CRC check |
|------------|-------------|-----------|---------------------------|-------------|----------|---------|-----------|
| 1st byte   | 2nd byte    | Bytes 3-7 | Bytes 8-9                 | Bytes 10-11 | Bytes 12-13 | Bytes 14-15 | Bytes 16-17 |

Figure 4. Circuit diagram of digital processing module.
3.5. Design of power supply module

![Circuit diagram of digital processing module.](image)

In this paper, the self-power supply mode is selected as the power supply scheme of the sensor. The circuit schematic diagram is shown in Fig. 5, including the power take coil, Rectifier Bridge, voltage stabilizing module and protection module [8]. The energy take-off coil is installed on the tested circuit, its output is rectified and filtered, stored by super capacitor, and then converted into ± 5V power supply through current limiting and power chip to supply power for the whole sensor system.

DB107 is selected as the rectifying device, whose withstand voltage reaches 1000V and rated current reaches 1A, which has a high safety factor. LM805 three terminal stabilized voltage integrated circuit is selected as the stabilized voltage power supply, which requires few peripheral components, and there are protection circuits of overcurrent, overheating and regulating tube inside the circuit, which has the advantages of reliability and convenience. SMBJ series TVS tube is selected as the protective device, which can effectively absorb current Impact energy.

4. Structure and protection design of sensor

4.1. Structure design of current sensor

The current sensor adopts non-contact design, which needs to establish stable position relationship between structure and conductor. In this paper, the opening and closing design is adopted to ensure the compression force when the structure is closed through the buckle, so as to ensure the stable installation of the equipment. Structural design diagram is shown in Fig. 6. The overall dimension is 70mm (height) × 60mm (outer diameter) × 30mm (inner diameter).

![Figure 6. Structural design diagram.](image)

4.2. Protection design

The current sensor mainly relies on the shell to provide insulation protection for the internal circuit, so the shell material needs to have better insulation performance. In this paper, polyhexamethylene diamine is selected as the shell material of current sensor after comprehensive comparison of material properties. The measured insulation resistance is greater than 20 mΩ, which can meet the insulation protection requirements of current sensor.

When the current sensor is applied in outdoor scene, it needs to consider the IP protection function. In this paper, the IP protection of the circuit is realized by filling. Silicone rubber is selected as the
potting material of the current sensor. After heating and curing, the current sensor can reach the protection level of IP67.

5. Sensor calibration and linearity test

After completing the design of the sensor device, three current sensor devices are made. The calibrated current sensor needs to be calibrated and tested for linearity before it can be used in the field.

The power frequency current source is used to calibrate the range of the sensor device. The calibration results of the phase a sensor are shown in Figure 12. The range is 30a, the sensitivity is 0.11v/a, and the linear fitting coefficient is 99.946%. The calibration test results of phase a sensor are shown in Fig. 7, with the maximum error of 0.76%, and the linear fitting coefficient between the measured current and the standard current is 99.998%. The test results show that the calibrated current sensor device has high accuracy and good linearity, which can be applied to the actual line current measurement.

![Figure 7. Sensor calibration and linearity test.](image)

6. Pilot application

In order to verify the long-term stability and reliability of the current sensor, the field pilot application was carried out. 10kV cable of transformer in distribution room is selected as current measurement object. The current sensor is fixed on the cable through the buckle structure. The field installation of the current sensor is shown in Fig. 8.

![Figure 8. Effective value of current](image)
Since the installation of the current sensor, it has been running stably for more than one year. The running state is normal, and it has good reliability and stability. The current sensor can collect the current waveform in real time, and calculate and output a valid value in 10 seconds. The current effective value and current waveform are shown in the Fig. 9 and Fig. 10 respectively.

At present, the distribution automation system collects and outputs an effective value every 15 minutes, which makes the short-term characteristics (actual current fluctuation in a short time) of the actual line lost, and only reflects the long-term characteristics of the actual line load. The current sensor device developed in this paper can collect the current data of very high frequency, and can effectively track and reflect the short-term characteristics of the circuit. Compared with the current transformer (CT) used in the distribution automation system, the current sensor device developed has the advantages of non-invasion measurement, convenient installation and layout, small size, remote intelligent management, etc., which can provide a more comprehensive and real-time data support for the transparency of the power grid.

7. Conclusion
In this paper, the intelligent micro current sensor is developed, and the key modules such as signal processing circuit, digital processing circuit, wireless communication module, self-power supply module are designed. The structure of the current sensor is designed and the insulation and IP protection scheme is formulated.

The intelligent micro current sensor shows good stability and reliability in the current measurement of 10kV cable of transformer in distribution room. The monitoring data is transmitted through wireless communication, which solves the problem of high and low voltage isolation faced by communication lines. The micro intelligent sensor has the comprehensive advantages of miniaturization, convenient installation, low power consumption and high integration, which can improve the transparency of power grid for more comprehensive and real-time data support.

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