Application of current sensor based on giant magnetoresistance effect in distribution network

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Abstract. Advanced sensing and measurement techniques are key technologies to realize a smart grid. With the advantages of having a high sensitivity, high linearity, small volume, and simple structure, the giant magnetoresistance (GMR) current sensor has broad application prospects in smart grid measurement and monitoring. This paper presents and studies a current sensor terminal based on giant magnetoresistance chip, the overall structure of the current sensor is designed, the power supply scheme and wireless communication scheme are formulated, the insulation protection and IP protection scheme of the current sensor are designed, and the current sensor terminal which can be used in the distribution network scene is prepared. The field response is carried out in the 10kV distribution transformer cable at last. The stability and reliability of the terminal operation are verified. The research results show that the current sensor developed in this paper has the advantages of convenient layout, stable operation and wireless communication. It can provide more comprehensive and real-time information support for the operation of distribution network and lay the foundation for the transparency of smart grid.

1. Introduction

Facing the increasingly severe challenges of energy development, energy-saving, green and sustainable smart grid and energy Internet are becoming the major scientific and technological innovation and development trend of the world's power system reform [1]. Constructing the "nervous system" (perception system) covering the key nodes of the power grid is the basis of developing the smart grid and further realizing the transparency of the smart grid. The perception of the voltage and current values of the key nodes is the key to the construction of the "nervous system" of power grid [2].

Current sensors include current transformers, Rokowski baseline coils, shunt resistors, fluxgate current sensors, Hall sensors and giant magnetoresistance sensors. Current transformers are widely used in power system to collect the current of key nodes, but they are bulky and must be prevented from being saturated when large currents occur. Sampling resistance method is mainly used in DC current, precision current and impulse current measurement and other fields. Rokowski baseline coil has the advantages of simple structure, low cost, small temperature drift and reliable performance. It will not be saturated without iron core and has fast frequency response. However, it has the disadvantage of not being able to measure DC current, and the measurement bandwidth has lower frequency limit and upper frequency limit. Fluxgate sensor has the advantages of high precision and
good stability, but it can only measure low-frequency small current, and it is expensive. Hall sensor is based on Hall effect. Because of its mature technology, simple structure and low price, it is widely used in occasions where the accuracy requirements are not very high. However, its measurement results are vulnerable to external magnetic field, and it has the disadvantages of large temperature drift and low accuracy [3, 4].

Distribution lines in power systems usually reach millions of kilometers in length, and the number of electrical equipment is huge and widely distributed. At present, there is no sensor to monitor the lines and equipment in real time. The existing current measurement methods do not meet the basic needs of smart grid for comprehensive and real-time sensing information, so it is urgent to develop new intelligent sensor devices [5].

In recent years, with the maturity of magnetoresistance sensor technology based on magnetoresistance effect, current sensor based on magnetoresistance effect has many advantages, such as small size, high sensitivity, low power consumption, low cost, good temperature stability, no AC/DC restriction, wide application scope, easy maintenance, multi-parameter measurement, etc [6, 7]. It is expected to be widely used to realize the current information of key nodes in the distribution network. The perception and construction of the "nervous system" of the power grid lay the foundation for the realization of the transparency of the smart grid [8].

In this paper, a current sensor terminal based on giant magnetoresistance effect is developed, and its stability and reliability are verified by field test. It can provide more comprehensive and real-time information support for the operation of smart grid and lay the foundation for the transparency of smart grid.

2. Design of current sensor

2.1. Architecture of current sensor

The current sensor system architecture based on giant magnetoresistance effect is shown in figure 1, which includes a set of chips, signal conditioning circuit, AD module, digital processing MCU, communication module and power module. The magnetic field signal generated by the measured current is transformed into voltage signal through giant magnetoresistance sensor chip. After analog signal processing by signal processing circuit, the signal is converted into digital signal by AD module and processed digitally by MCU. The processed data is uploaded to the receiving server by wireless communication module to collect and analyze the current signal [9].

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

2.2. Design of signal processing circuit

The magnetic field generated by conductor current is amplified by magnetic collector ring, measured by giant magnetoresistance sensor chip in the air gap of magnetic ring and converted into voltage signal. The output voltage of GMR chip is amplified, filtered and zeroed by signal processing circuit, and the final output voltage signal is obtained. The schematic diagram of signal processing circuit is shown in figure 2.
2.2.1. Design of signal conditioning circuit. Signal conditioning circuit adopts instrument amplifier structure, which can effectively resist common mode interference and has high input resistance, and improve signal-to-noise ratio. In this paper, a monolithic integrated improved three-op-amp instrument amplifier has better matching parameters and lower power consumption. In addition, because of higher integration, the error caused by resistance of the integrated instrument amplifier is smaller. The schematic diagram is shown in figure 3.

2.2.2. Design of filter circuit. A second-order low-pass filter with wireless gain is used in the filter circuit as shown in figure 4. The cut-off frequency is set to be 10 MHz, pass-band amplification factor to be 1 times, quality factor to be 0.707, and relevant parameters to be: $C_1 = 40 \, \text{pF}$, $C_2 = 40 \, \text{pF}$, $R_1 = R_2 = 1 \, \text{k}\Omega$, $R_3 = 620 \, \Omega$.

2.3. Design of power supply circuit

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**Figure 2.** Schematic diagram of signal processing circuit.

**Figure 3.** Schematic diagram of signal processing circuit.

**Figure 4.** Principle diagram of filter circuit.

**Figure 5.** Schematic diagram of power supply circuit.
The battery is used to supply power to the sensor system. The power supply circuit is shown in figure 5. The TVS tube is used to absorb the instantaneous surge impact in the rear stage of the battery, and then the voltage is stabilized by the voltage stabilizer chip to ensure the normal operation of the back stage circuit. According to the spatial layout of the structure, a polymer lithium battery with a size of 25 *20 *8 mm is selected. Its capacity is 200 mAh and the average power consumption is 1.2 mW. It can theoretically work for more than 15 days for the sensor system. The (+5 V) and (+2.5 V) voltages generated by the power module provide the operating voltage for the operational amplifier and the GMR chip respectively [10].

2.4. Design of digital processing module
When choosing MCU, memory, speed, peripheral requirements, development tools and compatibility should be considered. Nordic nRF52832 chip has built-in A/D and Bluetooth transmission module, the main frequency is up to 64 MHz. nRF52832 chips have the advantages of compact size, versatility and low power consumption, which can meet the processing requirements of sensors [11].

The communication module adopts wireless communication mode and does not need to arrange communication lines, which avoids the isolation of high-voltage terminal and low-voltage terminal. The design of communication module needs to consider the transmission rate and power consumption comprehensively. The wireless transmission rate of current sensor data is about 5 Kbps and the communication distance is about 10 m. nRF52832 chip has 512 KB Flash and 64 KB RAM, and has 2 Mbps/1 Mbps communication rate. In this paper CC2640R2F chip is chosen as the Bluetooth wireless communication chip. The schematic diagram of digital processing module is shown as figure 6.

![Figure 6](image_url)  
**Figure 6.** Schematic diagram of digital processing module.

2.5. Design of shell structure
The miniature smart sensor is designed in non-contact mode. The current is measured by measuring the magnetic field near the conductor. It needs to establish a stable position relationship between the structure and the conductor. The opening and closing design ensure the clamping force when the clamping is closed and the installation of the equipment is stable by increasing the clamping force. The structure of the equipment is shown in figure 7.
3. Field test and application

In order to verify the performance of the developed current sensor terminal, field application tests were carried out. The current sensor is installed at the incoming cable of 10 kV distribution transformer. The collected data are sent to the data system by wireless communication. The field installation diagram is shown in figure 8.

The test data of current sensor are shown in figure 9. From the figure, it can be seen that the developed current sensor can run stably for a long time and has high reliability. Compared with the traditional current transformer, the current sensor can measure higher frequency current, and has the advantages of small size, fast installation, no insulation problems, data remote communication and so on, which meets the needs of the development of smart grid.

4. Conclusions

In this paper, a current sensor based on giant magnetoresistance principle is designed. The signal processing circuit, including conditioning circuit and filter circuit, is designed to ensure that the frequency measurement range can reach 10 MHz, which solves the problem that the traditional current transformers are unable to measure high frequency current. Wireless communication module is designed to solve the problem of isolation between the high voltage end and the low voltage end caused by connecting the communication line.

The giant magnetoresistance current sensor terminal is manufactured, and field test is carried out in the 10 kV distribution application scenario. The test results show that the current sensor can accurately monitor the current of distribution lines and ensure reliable and stable operation.

The giant magnetoresistance current sensor developed in this paper is suitable for many high voltage power transmission and distribution applications, such as steady-state working current monitoring, transient fault current monitoring and so on. It provides a new idea for the field of current intelligent sensing.

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