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Research on hand-held power frequency electric field measurement safety warning system

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Abstract: In order to provide accurate safety distance and alarm information for distribution network patrol operators, it is of great significance to ensure the life safety of operators and reduce accidents. The system uses the principle that the conductor placed in the electric field will generate induced charge. The parallel plate capacitance sensor is used to measure the space electric field, and the sensor is calibrated. The field strength threshold of the safe distance of the 10KV transmission line is set. Finally, a set of handheld power frequency electric field intensity measurement system is developed. It is small and easy to carry. It can accurately measure the electric field intensity information at the current position, and display and provide threshold alarm function through LCD screen to provide safety guarantee for operators.

1. Introduction

With the rapid development of the global economy, the demand for electricity in all walks of life is showing explosive growth. In order to meet the growing demand for electricity supply, the scale of high-voltage distribution network is expanding rapidly[1]. In the face of the increasing demand for power supply and the increasing complexity of connection in distribution network, real-time monitoring, inspection and maintenance of distribution network is the key to ensure the stable operation of distribution network [2]. Traditional inspection work is carried out by operators wearing simple protective equipment for inspection and maintenance. However, due to the complex structure and connection mode of transmission lines in distribution network and the low professional level of operators, casualties often occur in the process of maintenance [2]-[3].Therefore, if the power frequency electric field around the power line can be accurately measured by the operator during the maintenance of the distribution network transmission line, and the real-time voice broadcast prompt or safety distance warning of the intuitive safety distance can be carried out, the unnecessary personal safety accidents caused by the misjudgment of the safety distance by the operator will be greatly reduced.

The volume and weight of the existing electric field measurement instruments are large, which makes it inconvenient to carry. During the maintenance process, it is extremely inconvenient for the maintenance personnel to cross the mountain and cross the mountain with the instruments with large volume and weight. Therefore, the hand-held distribution network power frequency electric field intensity measurement safety warning system designed in this paper is convenient to carry, with a length of 110 mm, a width of 50 mm, a height of 23 mm, and a weight of 86 g. It can accurately measure the electric field intensity information at the current position, and display it through LCD and provide threshold sound alarm function, which provides a reliable guarantee for the life safety of operators.

2. Measurement principle

According to the Gauss theorem, there will be induced charge on the metal plate in the electric field. The surface density of the induced charge is $\delta(t)$, where ε is the dielectric constant in the air [4], and ε_0 is the vacuum dielectric constant. The change of the intensity of the measured electric field causes the change of the number of induced charges. This relationship can be expressed as [5]:

$$Q(t) = \int \sigma ds = \varepsilon_0 E(t) S \tag{1}$$

In Eq. (1), $Q(t)$ is the induced charge of the plate; $E(t)$ is the measured electric field intensity; S is the effective area of the induction plate [4].

The structure principle of the induction unit is shown in Figure 1. The upper and lower plates are connected to both ends of the sampling capacitor Cs respectively. The voltage signal generated by the induced charge of the plate on the sampling capacitor Cs is used as the output signal [6]. The size relationship is:

$$U(t) = \frac{Q(t)}{C_s} \tag{2}$$

$U(t)$ is the output voltage. Substituting Eq. (1) into Eq. (2), we can get:

$$U(t) = \frac{\varepsilon_0 E(t) S}{C_s} \tag{3}$$

The electric field intensity of the measurement position can be obtained by the voltage at both ends of the sampling capacitor Cs[7]. The formula (3) establishes the relationship between the output voltage of the sensing unit and the detected electric field intensity. The information of the electric field intensity can be obtained by processing and calculating the output voltage signal of the sensing unit[8].

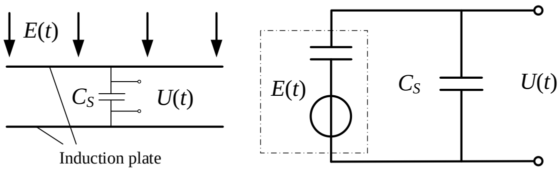

Figure 1: The schematic diagram of the induction unit structure and the equivalent circuit of the capacitive sensor

3. Hardware and software design

The power frequency electric field sensor system designed in this paper includes four parts: power frequency electric field sensing unit, front-end amplifier circuit, 50 Hz band-pass filter circuit, and rectifier circuit. The front-end amplifier circuit includes a voltage following circuit and a signal differential amplifier circuit. The block diagram of the power frequency electric field sensor system is shown in Figure 2. The output signal of the sensor is converted by AD, and the measured electric field intensity information can be analyzed and processed by single chip microcomputer. Finally, the liquid crystal is used to display the electric field intensity information, and the threshold alarm function is set. The safe distance of the voltage of 10KV is 0.7m. Therefore, when the distance from the field source is 1m, the sensor will alarm, leaving a margin to ensure the safety of the human body [8][9].

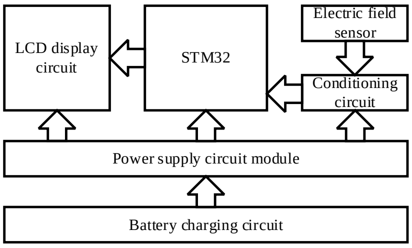

Figure 2: System block diagram of power frequency electric field sensor

The overall PCB circuit board is designed for the designed signal conditioning circuit. Considering the portability requirements of the power frequency electric field sensor, a smaller device package is selected when designing the circuit board. The voltage following circuit is composed of LM358 chip. The signal differential amplifier circuit uses AD620 as the chip of the differential amplifier circuit. The band-pass filter and full-wave rectifier circuit are built by using the LM324 chip of the four operational amplifiers. As shown in Figure 3, it is the schematic diagram of the signal processing circuit.

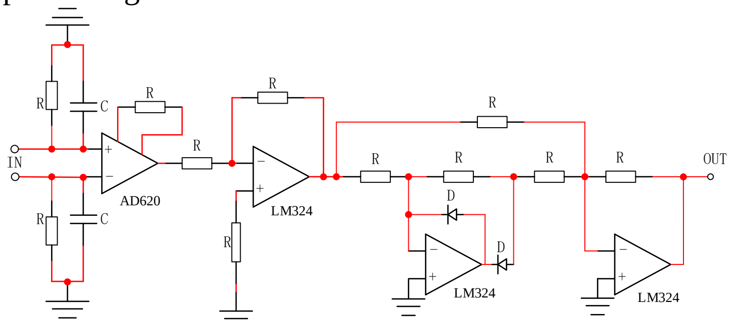

Figure 3: Principle diagram of signal conditioning circuit

Based on the advantages of low power consumption and high compatibility of STM32 microcontroller, the MCU module of this system adopts the MCU as the main control of the system. The battery is powered by a 3.7V lithium battery, and a charging module is designed to charge directly from the USB port. As shown in Figure 4, it is the schematic diagram of the overall circuit.

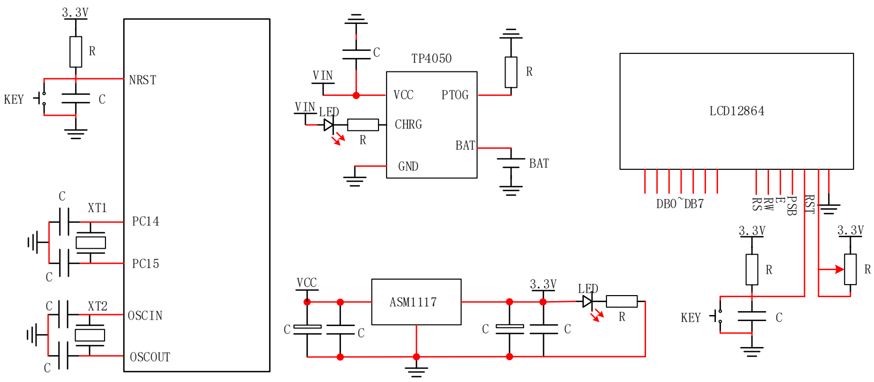

Figure 4: Overall circuit schematic diagram

The software system development environment uses Keil uVision5. The signal collected by the sensor is converted by the ADC inside the single chip microcomputer, and then converted into the field strength value through the corresponding algorithm. When the threshold is exceeded, the alarm is set. The overall circuit board and appearance are shown in Figure 5. The software flow chart is shown in Figure 6. The shell of the sensor is 110 mm in length, 50 mm in width, 23 mm in height and 86 g in weight. Easy to carry, and low cost.

(a) The overall circuit board (b) The front and back of the sensor

Figure 5: Overall circuit board and overall appearance of sensor

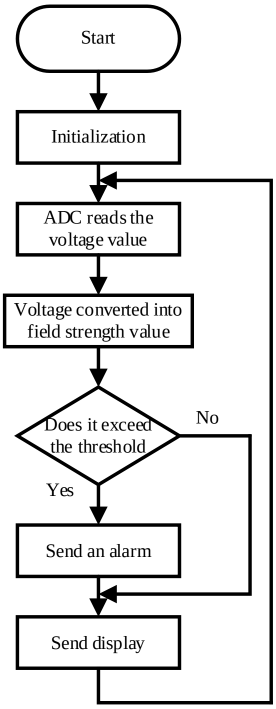

Figure 6: System flow chart

4. Experiments

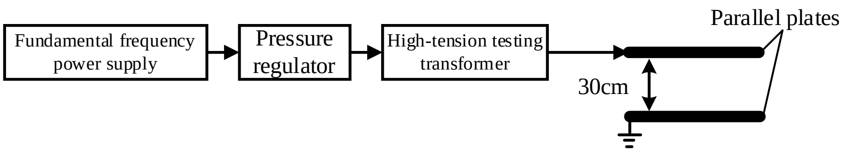

Figure 7: Test platform

Firstly, the electric field sensor is calibrated. The test platform is shown in Fig. 7. The sensor is placed in the middle of the large parallel plate. The upper plate of the parallel plate is processed with high frequency and high voltage, and the lower plate is grounded. In this way, a uniform electric field will be generated inside[10][11]. After the power frequency power supply is boosted, the corresponding field strength value is obtained after $E = U/d$ calculation. The data collected by the sensor are as follows Table 1:

Table 2: Output voltage and field strength

The applied electric field strength(KV/m)	output voltage(mV)
17.33	606
34.67	1250
50.67	1800
67.33	2440
84.00	3130

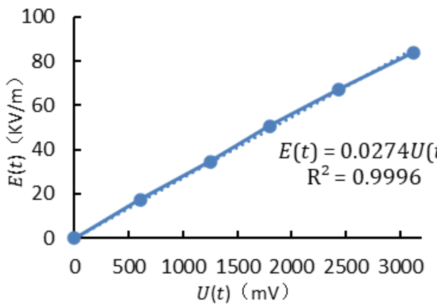

Figure 8: Relationship between output voltage and electric field intensity

As shown in Figure 8, the output data of the calibrated sensor can be obtained:

$$E(t) = 0.0274U(t) \tag{4}$$

$E(t)$ is the electric field intensity, $U(t)$ is the output voltage, where $R^2 = 0.9988$, the linearity of the sensor is good.

The test platform is adjusted to 10kV as the field source, and the relationship between the output field strength of the sensor and the distance is measured. As shown in Table 2:

Table 3: The relationship between the output field strength of the sensor and the distance

Distance from field source $E(t)$ (m)	Output electric field strength X (kV/m)	Alarm condition
0.4	8.4392	Yes
0.7	6.302	Yes
0.8	5.8088	Yes
1	4.8224	Yes
1.2	4.355	No
No	4.0552	No

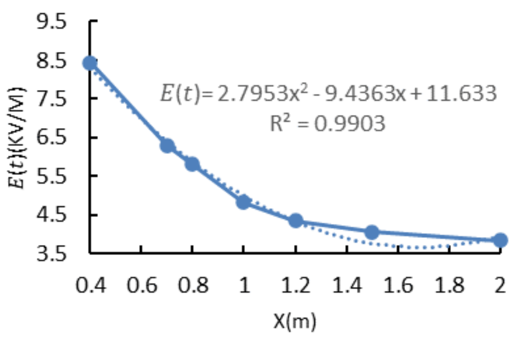

Figure 9: The relationship between the electric field intensity and the distance of 10KV field source

According to Table 2, as shown in Figure 9, the relationship between electric field intensity and 10KV field source distance is constructed. Therefore, the relationship between the electric field intensity and the distance of 10KV field source can be obtained as follows:

$$E(t) = 2.7953x^2 - 9.4363x + 11.633 \quad (5)$$

X is the distance from the field source, and its $R^2 = 0.9903$. Therefore, the fitted function is more suitable for the data. It can measure the electric field generated by 10KV power frequency high voltage field source. And when the sensor is 1m away from the field source, it can accurately alarm and meet the design requirements.

5. Conclusion

In this paper, based on the principle that the conductor under the electric field will produce induced charge [4][12] a parallel plate capacitive sensor is used to measure the space electric field, and the sensor is calibrated. The field strength threshold of the safe distance of 10 kV transmission line is set. Finally, a set of hand-held distribution network power frequency electric field strength measurement safety warning system is developed. It is 110 mm long, 50 mm wide, 23 mm high, 86 g heavy, easy to carry, and can accurately measure the current position of the electric field strength information, and through the LCD display and provide threshold sound alarm function, for the operator 's life safety to provide a reliable guarantee.

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