# Application and Research of RFID Sensor in Switchgear

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**Abstract:** Switchgear is a metal enclosure fully enclosed equipment; the temperature measurement of key points in its internal structure has always been a difficult point in the operation and inspection of power equipment. Aiming at the drawbacks of traditional temperature measurement methods, a passive wireless temperature measurement scheme based on the RFID temperature sensor is proposed. The biggest problem of using the RFID temperature sensor is how to ensure reliable transmission in a fully enclosed metal environment, which depends on the antenna design and antenna installation position of the RFID temperature sensor, as well as software algorithm, so as to ensure the reliability of wireless data transmission.

## 1. Introduction

As important equipment in the distribution network and because of its enclosed metal structure, the temperature measurement of internal key points in switchgear has always been a difficult point when condition monitoring happens. There are mainly two methods for internal temperature monitoring, which include surface acoustic wave method and Radio Frequency Identification (RFID). Surface acoustic wave method is a passive sensing technology which is free from the sensor power supply problem. Having said that, limited by the frequency division and cutting principle of signal metering and signal simulation processing technology, that method is vulnerable to external electromagnetic interference, false positives and poor expandability. Against that backdrop, RFID has been gradually applied in condition control of switchgear thanks to its passive wireless temperature measurement principle using digital temperature measurement and digital transmission, combined with the sensor's own identification.

There exist two hidden dangers in traditional temperature measurement methods which equipped with sensors .The first is outermost circle of plum blossoms that affects the safety distance. The second is the unstable installation which risks falling. To avoid from changing parameters and characteristics of the original contacts in the switchgear, we have proposed a smart and integrated temperature measurement method.

## 2. The basic structure and operation principle of the sensor

Based on the radio frequency identification technology which can make the temperature sensor work and realize the wireless transmission of the temperature data, the system of sensor temperature measurement mainly composes the temperature reading and writing module and the identification module, as shown in Figure 1.

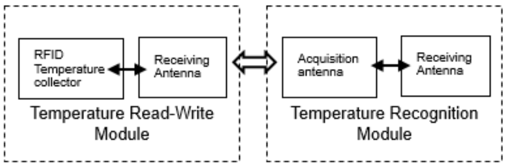



Fig.1 Structure of RFID temperature measurement system

As shown in FIG. 1, the reading and writing module of the RFID temperature measuring system includes a temperature collector and a receiving antenna, a temperature detecting module temperature measuring sensor and an collecting antenna. The temperature sensor can be embedded, glued or bundled on the objects that need to be detected, and the core of the temperature is an RFID temperature measuring chip within a working frequency band of 915 MHz. Its operation principle is shown as in Fig. 2.

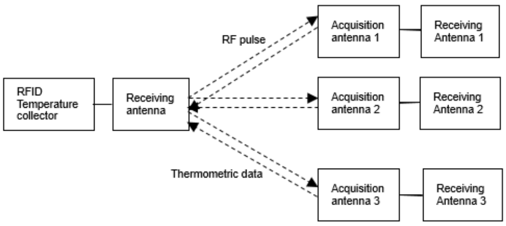
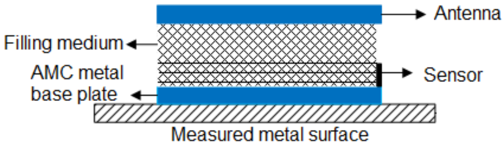



Fig.2 Principle of RFID temperature measurement

As shown in FIG. 2, the temperature reading and writing module produces a carrier signal which can be transmitted through its antenna, and the identification module sensor is responsible for receiving the signal, and sends the ID and temperature information stored in the chip that based on the energy obtained by the induced current; After reading and decoding the information, the reading and writing module will sent to the upper computer for data processing.

As the core of RFID, RFID temperature sensor works inside the switchgear featuring strong electromagnetic, making insulation margin and anti-electromagnetic interference considered. ABS(Acrylonitrile Butadiene Styreneplastic) package of AMC structure is usually used. As shown in Fig.3, the AMC structure consists of three parts whose uppermost layer is an antenna and the bottom is a periodically arranged metal patch, and the filling medium is in between .And the metal via connects metal patch and the floor.




(a)Sensor structure

(b)Sensor picture

Fig.3 RFID temperature sensor

The main advantages of the ABS package are: (1) The temperature of the RF tag is measured by the wired thermistor installed near the key point. The connection line can not be exposed because of the high voltage, making the ABS package case insulated. (2) The package covering uses AMC structure, making less interference of metal on the label and improving the readability of the label. At the same time, the metal layer laid on the bottom of the designed package boasts good thermal conductivity to the temperature measurement of thermistor. (3) The label is easy to install after being packaged. The main merits that using a piece of plum touch finger are:(1) The sensor and the contact are integrated, making appearance unchanged.(2) The outermost ring of the sensor does not go beyond the outermost ring of the contact, causing no affect on the electrical characteristics.(3) The installation and fixing method are the same as the fingertip, making no loosen under the mechanical vibration of the closing and opening switch.(4) The ventilation and heat dissipation remain the same.

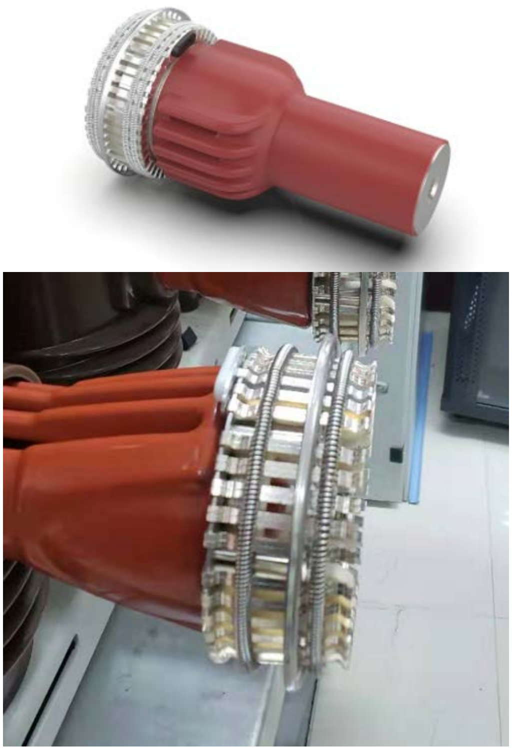


Fig.4 Integrated temperature measuring device

### 3. Research on layout of RFID temperature sensor

Because of the electromagnetic shielding that brought by fully enclosed metal structure of the switchgear, the receiving antenna and the collecting antenna are usually installed in the same compartment. Generally speaking, the receiving antenna is installed on the top of the busbar room, and the collecting antenna and the sensor are installed in a high-voltage contact or a cable connector. The collector is located in the instrument room and can be connected to the receiving antenna by coaxial cable. The temperature can be seen on alive display, as shown in Figure 5.

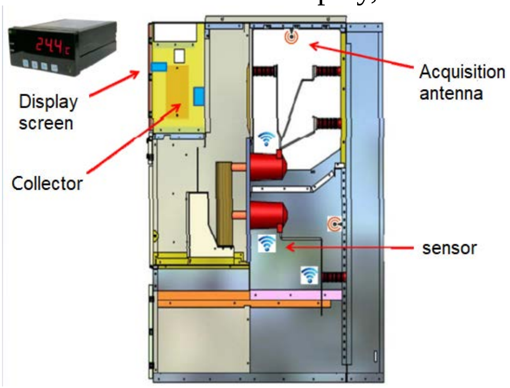



Fig.5 Installation schematic of RFID temperature measurement system

As the receiving antenna and the collecting antenna communicate via radio frequency electromagnetic waves, however, when the electromagnetic wave spreads over the switch cabinet, the metal reflects the ultra-high frequency band, but also disturbs the original RF energy absorption function of the RFID reader antenna, and causes eddy current around the reader, reducing the overall performance of the RFID field. These eddy currents also produce a magnetic field that is perpendicular to the metal surface, which will defection the reader region. Metal can also breed additional parasitic capacitance (ie, energy loss due to electromagnetic “friction” caused by metal), causing imbalances between the reader and tag antenna and further undermining performance of the whole system. In some frequency bands, the energy reflected back by the metal will interfere the tag and the reader. All those show that using RFID in an environment with a large amount of metal materials will greatly reduce the actual rate, distance and reliability in read and write rate, which is far lower than the results in the laboratory.

Calculate the tag receiving energy value at the distance reader according to the Friis equation

$$P_{th} = P_t G_r \frac{A_e}{4\pi r^2} = P_t G_r G_t \left(\frac{\lambda}{4\pi r}\right)^2 \left(1-|s|^2\right) \quad (1)$$

Gr and Gt mean the gains of the receiving antenna and the collecting antenna respectively; Pt represents the transmitting power of the reading and writing module; s is the complex power wave reflection coefficient.

Use radar ranging equation

$$P_r = \sigma \frac{G_r G_t}{4\pi}\left(\frac{\lambda}{4\pi R^2}\right) P_t \quad (2)$$

σ is the radar cross section of the label

The tag can only be sensed when the energy Pr received by the antenna is more than $P_{th}$ and $P_{min}$. From equation (2),we conclude the following equation

$$R_1 = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_r G_t (1-|s|^2)}{P_{th}}} \quad (3)$$

$$R_2 = \sqrt{\frac{\lambda}{4\pi}\left(\sigma \frac{P_t G_r G_t}{4\pi P_{min}}\right)^{1/2}} \quad (4)$$

In equations (3) and (4), R1 is determined by the minimum threshold power $P_{th}$ and R2 is determined by the receiver sensitivity $P_{min}$ , and a small value is used for the estimated value of the final communication distance, which ranges between 2.3 meters and 6.7 meters, as shown in Figure 6.

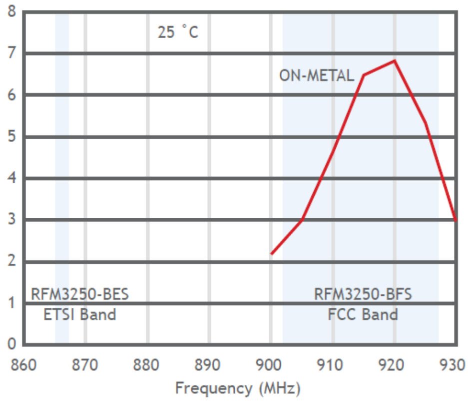



Fig. 6 Estimated distance of system theoretical communication

Suppose that the switch cabinet is an ideal conductor with infinite conductivity and the incident field is E:

$$E_i = \sqrt{1+K^2}\cos\omega t \quad (5)$$

$$\bar{a}_i = \bar{a}_x\left(\frac{1}{\sqrt{1+K^2}}\right) + \bar{a}_y\left(\frac{K}{\sqrt{1+K^2}}\right) \quad (6)$$

$$\vec{E}_i = \bar{a}_i E_i = \bar{a}_{ix} E_{ix} + \bar{a}_{iy} E_{iy} \quad (7)$$

$$E_{xi} = \cos\omega t \quad (8)$$

$$E_{yi} = K\cos\omega t \tag{9}$$

If there is no loss on the reflecting surface, the reflection field is

$$\vec{E}_r = \vec{a}_x E_{xr} + \vec{a}_y E_{yr} \tag{10}$$

The reflection field orthogonal to the incident field is:

$$\begin{aligned} E_{r\perp} &= \left[\vec{a}_i \times \vec{E}_r\right] \times \vec{a}_i \\ &= \left[\frac{2K}{\sqrt{1+K^2}} \sin\left(\omega t + \frac{\phi_x + \phi_y}{2}\right) \sin\left(\frac{\phi_y - \phi_x}{2}\right)\right] \vec{a}_\perp \end{aligned} \tag{11}$$

The effective values of the orthogonal reflection field are:

$$[E_{r\perp}] = \frac{\sqrt{2}K}{\sqrt{1+K^2}} \sin\left(\omega t + \frac{\phi_x + \phi_y}{2}\right) \sin\left(\frac{\phi_y - \phi_x}{2}\right) \tag{12}$$

We can conclude that the wireless wave has lower efficiency and severe interference. However, in particular areas, wireless wave are strengthened in a certain direction because of overlapping signals.

Various connections can see the temperature sensitive points of the high-voltage switchgear. The temperature sensor and the labels can be installed at the temperature sensitive points and the joints respectively. The reader antenna is located in the same cavity of switch cabinet and the sensor. The antenna wire can be connected to the reader with the hole on the door. Thanks to the existing RF connection between antenna and the tag, the communication distance will not be influenced by the installation position of the reader, leaving the reader installed in different cavities through the antenna feeder. Taking the interference that metal brings to passive tags and the distribution of temperature nodes in different air cells into consideration, we may add redundant antennas to expand the communication range.

As the sensor is installed in the contact protector, whose front side is a metal reflective layer ,making distance uncontrollable and the multiple times of reflections in the metal cavity, we conclude that the best position of the receiving antenna is on the side and perpendicular to the sensor at the same time. The antenna can find its ideal location at the bottom which is one-third of the length of the cavity, which can bring strongest signal.

(1) Performance test on temperature measurement

In order to test the performance of the temperature label, the real temperature and the measured data of the three sensor samples are compared at different temperatures, as shown in Fig. 7.

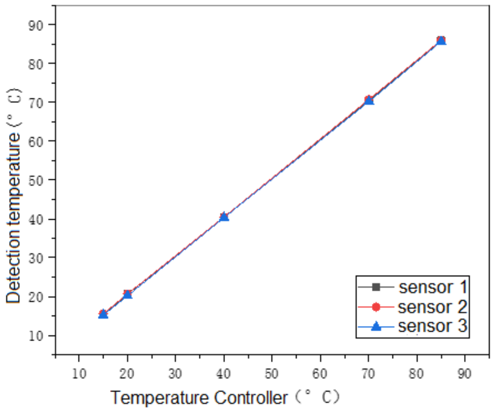



Fig. 7 Experimental results of temperature measurement by sensors

It can be seen from Fig. 7 that the three sensors all behave well in temperature measurement within 1 °C error .Temperature increasing causes the decreasing of sensor's receiving sensitivity. Above 75 °C and will be more likely to see overheating phenomenon of the switchgear, the deviation value of 1 °C can reflect the current state of the switchgear.

(2)Comparison of received signals at different locations

In order to compare intensity of the received signal at the different places, (upper contact A phase), (upper contact B phase) and (the upper contact C phase) is installed with a temperature sensor respectively at different temperatures (15 ° C, 20 ° C, 40 ° C, 70 ° C and 80 ° C). Figure 8 shows the test results.

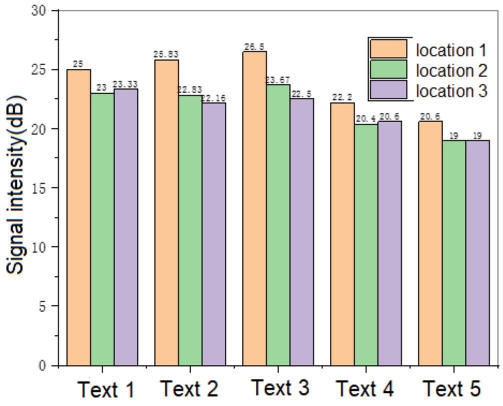



Fig. 8 Comparison of received signal strength at different installation locations

Figure 8 shows the comparison of signal strength monitored by temperature reading and writing module when the sensor scatters in three different places. The results demonstrate that the signal intensity ranks from position 1, position 2 to position 3, meanwhile position 1witnesses strongest signal intensity.

(3) Influence that the location of the receiving antenna brings to the signal strength

To compare the signal strength in different installation places, the antenna goes from the innermost of the short-circuit chamber to outer place.

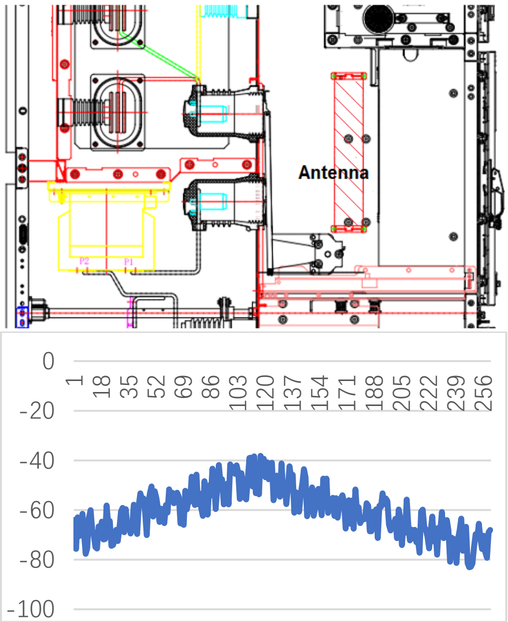



Figure 9 Influence of installation position of receiving antenna on signal strength

As the Fig. 9 shows that the best signal happens when the receiving antenna is located about 110 mm from the innermost side of the circuit breaker chamber.

## 4. Conclusion

This paper mainly introduces the basic principle of RFID. Based on RFID principle, we have also analyzed the transmission characteristics of wireless signals in the switchgear and designed the integrated temperature sensor of the switchgear contacts. By data analyzing and optimizing, we have drawn the following conclusions:

1) The designed sensor behaves well in sensitivity with1 °C error, making accurately detect the

temperature of the switchgear possible.

2) Taking advantage of original installation and fixing method can make the sensor fixed and reliable.

3) That method can realize the integrated design of the contacts, minimizing the bad influence on the contacts.

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