Research on Temperature Monitoring Method and System Design for Key High Voltage Equipment of Wind Farm

Baoyu Xie*

Guodian power Hunan new energy development Co., Ltd., Wangdefu international building, Wanjiali Road, Furong district, Changsha City, Hunan Province, 150090

*Corresponding author: xie_baoyu@sgcc.com.cn

Abstract. This paper focuses on the temperature detection of high-voltage equipment in wind power plant, puts forward the surface acoustic wave measurement method, and deeply studies the design process of surface acoustic wave sensor device and the design scheme of monitoring system. In different process materials of piezoelectric substrate and antenna design mode, there will be great differences in the transmission efficiency and anti-interference ability of surface acoustic wave. Therefore, the influence of surface acoustic wave on the performance of surface acoustic wave sensor device is possible Testing and setting the surface measurement parameters can improve the measurement performance. In the aspect of detection system, the typical key temperature monitoring equipment of high voltage switch cabinet in wind farm is selected to form a practical deployment scheme, which realizes the integrated functions of automatic temperature measurement, parameter optimization and adjustment, alarm and so on. The research and design method in this paper has great practical application value in the operation and control of new energy system.

Keywords: Wind farm, High voltage switchgear, Surface acoustic wave, Finite element simulation, Temperature.

1. Introduction

Wind energy resources are generally distributed in open places, with few people and harsh environment, which poses a certain challenge to the operation and management of key high-voltage equipment in wind farms. One of the most common operation problems of high-voltage equipment is heating [1]. Overheating of components will cause a series of faults of different levels. Therefore, for most unattended wind farm operation environment, fully intelligent devices and systems with high detection sensitivity, strong anti-electromagnetic interference and easy measurement should be installed to monitor the real-time operation temperature of high-voltage equipment without human intervention. It can automatically judge whether there is operation risk and avoid the heating fault of wind farm under long-term high-voltage operation [2].

2. Measurement principle and performance analysis of surface acoustic wave

Surface acoustic wave (SAW) is literally a form of sound wave formed in the process of propagation on the surface of elastic medium. As a signal transmission carrier, sound wave can realize the
transmission of signal from the measured end to the monitoring end. Surface acoustic wave (SAW) has many kinds of waveforms, such as Rayleigh wave, Lamb wave, love wave and so on. When measuring the mechanical changes of the dielectric surface caused by the changes of the environmental temperature, current, voltage, electromagnetic field and other parameters of the object, this change causes the elastic changes on the dielectric surface and forms the Rayleigh wave displacement components in different directions [3], which are generally composed of two shear waves parallel to the surface and longitudinal waves perpendicular to the surface. The generation principle of Rayleigh wave is shown in the figure below:

![Fig. 1 Force decomposition method of infinitesimal volume element](image)

The change of any external parameter acting on the elastic surface reflects the change of micromechanics. The surface of the medium is abstracted as an infinite unit volume element in the figure. The forces acting on the six sides of each volume element are projected onto the plane as the above three shear forces. Choosing the positive direction of the $X$ axis as the benchmarking direction, the surface stress synthesis can be expressed as follows [4]:

$$ F = \left( \frac{\partial T_x}{\partial x} + \frac{\partial T_y}{\partial y} + \frac{\partial T_z}{\partial z} \right) \Delta x \Delta y \Delta z $$

(1)

$F$ is the surface stress produced by the dynamic value of the acoustic surface sensing measurement. According to Newton's second mechanical force, equation (1) can be converted into a dynamic equation [5]:

$$ F = ma = \rho V^2 \frac{\partial^2 l}{\partial t^2} $$

(2)

Where $\rho$ is the density of the surface medium, $V$ is the velocity of the surface acoustic wave, $l$ is the displacement in the direction of the combined force, and $t$ is the action time. The stress in elastic medium is closely related to the medium density. The higher the medium density is, the greater the elastic stiffness is [6]:

$$ \rho \frac{\partial^2 l}{\partial t^2} = k \frac{\partial^2 l}{\partial (xyz)^2} $$

(3)

$K$ is the elastic stiffness parameter of the medium. In piezoelectric materials, electrical parameters and mechanical parameters such as stress are positively coupled. Therefore, when the stress is converted into an acoustic signal, it is necessary to choose the higher $K$ value, the higher the conversion efficiency. In addition, the surface acoustic wave transmission rate $V$ is also a key parameter in the measurement process. The faster the propagation speed is, the lower the transmission loss is [7], and the higher the transmission efficiency is. The propagation rate factor is also considered in choosing Rayleigh wave.
3. Key process design of SAW sensor

According to the measurement principle of saw, the detection and carrier device of saw excitation source is designed to ensure the safe and stable transmission process of signal from the transmitter to the receiver. In order to better design the sensor detection device, firstly, the signal shape change process of detection parameters is deeply analyzed, and the selection of appropriate excitation and bearing medium and structure conforms to the signal performance characteristics. The signal morphological transformation is shown in the figure below:

![Fig. 2 Signal conversion form](image)

The sensor assembly is designed based on the transition process of the transmitted signal state, as shown in the figure below, which is mainly composed of four parts: loop antenna, piezoelectric substrate, reflection grating and cross transducer.

![Fig. 3 Structure of SAW sensor assembly](image)

(1) The common antennas used in SAW sensor include spiral antenna and ring antenna. In this paper, the ring antenna has stronger anti electromagnetic interference ability than spiral antenna, which is more suitable for high-voltage power system applications, and can better avoid the energy loss caused by high-voltage electromagnetic field environment in the process of acoustic and electrical signal propagation. The small loop antenna has strong anti-noise ability, can shield the interference noise in the resonant cavity, and can separate the electromagnetic components with good shape.

(2) The piezoelectric substrate is made of LiNbO₃ as the basic material. The acoustic surface relies on the substrate component. When the temperature changes, the magnetic field of piezoelectric materials will shift in frequency. The coupling coefficient of LiNbO₃ can reach about 5, which is more than twice that of quartz.

(3) The reflection grating is a kind of grating structure which is etched on the piezoelectric substrate and composed of metal film motor. The saw is transmitted in the reflection grating. The higher the acoustic transmission rate is, the shorter the length of the grating structure is. The structure can be achieved by setting the length of the grating structure according to the different substrate materials Optimization of design.

(4) The cross transducer is also a component on the piezoelectric substrate, which is similar to the sensing contact. It can sense the external temperature environment parameters, sample and convert the external energy into the identifiable energy parameters of the piezoelectric material, that is, the energy form conversion process described in the previous paper is realized in the transducer.

4. Temperature measurement requirements and system design of key high voltage equipment in wind power booster station

According to the deployment of a typical switch cabinet component in the wind power booster station, it is generally composed of 6 circuit breaker contacts, 3 incoming bus bars, 3 outgoing cable heads and 3 current transformers. A set of SAW sensors designed above are installed on all key components to
sense and collect the operating temperature of the components. The specific deployment model is shown in the following figure:

![Fig. 4 Design of temperature measurement system for switch cabinet of wind farm](image)

The sensor body should be miniaturized as far as possible. The antenna and contact components can be installed separately according to the actual environment. The ring antenna is generally installed in the empty place of the surrounding environment to avoid affecting the signal receiving and transmitting. The sensor contact can be stably installed in the groove of the firmware to avoid loosening.

Generally, the reader is close to the wall of the switch cabinet, which can better communicate with the remote-control unit. Its main function is to gather the sampling data of 12 internal sensors and simple conversion processing, as a relay unit to complete the signal upload and release. The reader is also composed of two parts, antenna and integrated device. The design model is shown in the figure below:

![Fig. 5 Structure design of reader](image)

Reader antenna needs better antenna gain, anti-interference and omnidirectional. In this paper, the design mode of cylindrical omnidirectional antenna is selected. Compared with the flat antenna, the cylindrical antenna is smaller in size, not limited by the number of oscillators, has good frequency characteristics, higher antenna gain, and can receive electromagnetic signals in different frequency bands. The antenna is stably fixed in the platform area of the switch cabinet through an insulating base [9]. The design size of the cylindrical antenna is directly related to the gain value. Before the design, it is necessary to simulate and model the electric field of the antenna, set different permittivity, and calculate the gain of the high and low frequency bands through the equalization scheme, so as to reduce the attenuation performance of the high frequency band. The optimized antenna has a gain of 6dbi and a reflection coefficient of ~ 3db, which can effectively guarantee the electromagnetic signals in all directions of the link. The signal processing part of the reader filters and amplifies the received multi-sensor signals. The standard LO signal source is set to correct the frequency offset of the
acoustic signal. When the preprocessed signal completely meets the requirements of the standard signal, it is uploaded to the background system to realize the positioning and stable convergence transmission of multi acoustic signal [10-11].

The system detection platform mainly completes the signal acquisition, storage and display of surface acoustic wave temperature measurement process, and can analyze the propagation characteristics of surface acoustic wave signal. The platform stores the acoustic electric coupling algorithm model, which can accurately convert the collected voltage signal into temperature value, so as to express the real-time characteristics of temperature by various display methods. According to the relationship between the temperature and fault characteristics of each component of the switch cabinet, the regular alarm threshold is designed, and the early warning system can display the field temperature in real time. However, due to the frequency offset of piezoelectric materials in the process of temperature change, this frequency offset law will be stored in the system in advance. The control system finds the offset amplitude according to the signal frequency comparison. When the amplitude exceeds the normal range, the adjustment coefficient can be designed and sent to the reader to adjust the frequency value of the local oscillator signal and realize the real-time correction of the frequency offset signal.

5. Function test of temperature measurement system based on saw

In order to verify the functional characteristics of the saw detection device and system platform designed in this paper, a simulation test environment is built in the laboratory, the circuit breaker is selected as the typical test object in the switch cabinet, and four SAW sensors are deployed, which are placed in the temperature control box, so that the temperature of the test environment can be accurately adjusted and learned through the computer. In order to fully verify the functional characteristics of the saw temperature measurement system, the sensitivity, linearity, response time and detection accuracy of the system are comprehensively evaluated.

Four sensors are connected to a reader and a detection system, and the reader is also placed in the stability control box, which can also verify its high temperature resistance performance. The results of the four detection signals are recorded and calculated, which are summarized as follows:

| Tab. 1 Test results |
|---------------------|
| sensor1 | sensor2 | sensor3 | sensor4 | mean value |
| sensitivity 6.98kHz/℃ | 7.07kHz/℃ | 7.35kHz/℃ | 7.10kHz/℃ | 7.11kHz/℃ |
| Linearity 95% | 98% | 94% | 98% | 96.25% |
| response time 1.98s | 2.13s | 2.34s | 1.69s | 2.03s |
| Check the accuracy 2.49% | 3.53% | 2.33% | 2.49% | 2.71% |

It is obvious from the results in the table that the four detection functions of the four sensors of the same type all meet the detection conditions of the wind farm. The sensitivity of the wind farm is lower than 10kHz/℃, the linearity is higher than 90%, the response time is less than 3s, and the detection accuracy is less than 5%. It can be seen that the average measurement value of the surface acoustic wave temperature measurement system is lower than the standard value, indicating that the measurement process is stable and reliable, but the next step is not enough. It needs to be tested in the field operation environment.

6. Conclusions

In this paper, the measurement scheme of surface acoustic wave technology based on the application requirements of temperature monitoring of high voltage equipment in wind farm is carried out:

(1) LiNbO3 is selected as the piezoelectric substrate material, which is more stable and preferred than other materials in the aspects of surface acoustic wave propagation velocity, electromechanical coupling coefficient, temperature stability, propagation loss and dielectric constant;
(2) Choosing the loop antenna as the receiving unit of sensor module has more advantages than other directional antennas in terms of structure design, installation difficulty and signal transmission stability;

(3) The cylindrical omnidirectional antenna is more suitable than the plate antenna in antenna gain, standing wave ratio and receiving efficiency;

(4) A signal preprocessing module is designed for the reader to realize the frequency adjustment of the acoustic signal. The standard signal source is used as the reference value to correct the frequency offset within the adjustable range in real time;

(5) The system design platform can comprehensively analyze, calculate and display the propagation characteristics of the saw monitoring data, and control the important parameters of the front-end equipment, so as to realize the remote self-service remote control.

Based on the design of the device and system in this paper, the performance test in the laboratory stage is carried out, and the test results can meet the application standard requirements of wind farm temperature monitoring. However, due to the differences between the field environment and laboratory conditions, the system should be further deployed in the field to verify the normal range of environmental tolerance, reliability and functional indicators of the equipment, so as to gradually adapt to the environment Different wind power plant application environment.

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