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# Line Breeze Vibration Monitoring System Based on NB-IoT Communication Module

Jie Sun, Hao Li, Xinbo Sun, Jitao Li

*State Grid Heilongjiang Electric Power Company Qiqihar Power Supply Company, Qiqihar 161005, China*

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ABSTRACT

The transmission line will produce the phenomenon of breeze vibration under the influence of the environment, and the long-term breeze vibration will cause damage to the transmission line, and then cause immeasurable economic losses. Given the problems of the existing transmission line breeze vibration monitoring system, such as single monitoring mode, insufficient monitoring accuracy, complex communication mode, real-time online monitoring, and early warning, a new line breeze vibration monitoring system based on NB-IoT communication module is proposed. The system uses an STM32F103C8T6 embedded microcontroller and micro-electro-mechanical System (MEMS) accelerometer sensor to collect real-time line status data. The data is reported to the OneNET cloud platform through the narrowband IoT private network to achieve online monitoring of line vibration status. After testing, the line vibration monitoring system has the advantages of real-time data reporting, high accuracy of output data, and low power consumption. The system works stably and can monitor the vibration state of transmission lines in real-time and complete early warning and other functions, which can promote the prevention of line vibration and strand breaking and maintain the safe operation of the power system.



## 1. Introduction

With the rapid development of China's power grid construction project, the effective monitoring of the actual operation of transmission lines has become the focus of the production and operation units. In the construction of a high-voltage power grid, power failure caused by breeze vibration will cause serious economic losses. Breeze vibration is the high frequency and small amplitude vibration of the line caused by the "Karman vortex" after the breeze blows through the wire. The phenomenon of breeze vibration has a certain invisibility, which is difficult to be detected by the naked eye. In the long run, it will accelerate the fatigue strand breaking and wear failure of overhead wire and fiber composite overhead ground wire and also cause fatigue damage or wear of anti-vibration hardware such as anti-vibration hammer, which greatly weakens its anti-vibration performance and seriously jeopardizes the safe operation of transmission lines. Therefore, it is particularly necessary to effectively monitor the breeze vibration of the wire [1-2].

At present, many scholars at home and abroad have done a lot of research on transmission line condition monitoring methods. Zhao Junan et al. [3] designed an online monitoring system for AC transmission line vibration based on ZigBee technology to realize real-time monitoring of the breeze vibration state of the line. However, the development process of the upper computer is cumbersome and multiple devices cannot be monitored simultaneously. Cheng Wenfeng et al. [4] researched and developed a transmission line breeze vibration monitoring device based on the Remote Wireless communication module (LoRa), and demonstrated through experiments that this device can monitor the line in real-time. However, the shortcoming of the communication method is that the communication distance is short, and gateway networking is needed for long-distance communication. Cao Kangqi et al. [5] proposed a transmission wire breeze vibration detection technology based on thermal imaging cameras, but the monitoring equipment is easily affected by the environment, and the temperature of the transmission wire is more affected by rain and snow, so the vibration monitoring of the transmission wire cannot be effectively carried out. With the rapid development of sensor technology and Internet of Things technology, real-time online monitoring systems have gradually become an effective means of transmission line monitoring, which is embodied in system acquisition terminal and wireless communication technology. In terms of system acquisition terminal, literature [6] proposes a line condition monitoring system based on MEMS sensors to collect vibration amplitude and surrounding environmental parameters of transmission lines. In terms of wireless communication, ZigBee technology and LoRa technology are

* Corresponding author.
E-mail addresses: 1443345723@qq.com (J. Sun)
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respectively adopted in literature [3] and [4], but the communication distance of these two technologies is relatively short, the networking is complex, and there are certain limitations in deployment. Some transmission lines are distributed in remote mountainous areas, so the monitoring system needs to choose a reasonable communication mode to ensure that the demand is met.

Aimed at the problems existing in the monitoring method of line state, design a kind of based on NB - IoT (narrowband internet of things) communication module circuit breeze vibration monitoring system. The communication mode of this system is the NB network, which relies on the mobile network. Each node can be regarded as a gateway and report data independently, avoiding data collision and data loss caused by LAN networking.

With the STM32F103C8T6 chip and BC26 module as the core, the system acquisition terminal device collects the vibration state data of the line through the acceleration sensor and filters it through the FFT algorithm based on wavelet noise reduction to realize the output of high-precision data. Data is reported to the OneNET cloud platform through the BC26 module using NB-IoT communication technology for monitoring, realizing real-time online monitoring of transmission line vibration status, which is of great significance for preventing transmission line breakage and maintaining safe operation of the power system.

## 2. System architecture design

The line vibration monitoring system establishes the IoT architecture of the perception layer, network layer, and application layer. The data acquisition board of the sensing layer is designed with embedded microcontroller hardware and software. It is mainly responsible for collecting related data on line vibration. It is composed of an acceleration sensor, a microcontroller unit (MCU), NB module, etc. To extend the service time of the acquisition terminal, lithium battery packs, and solar panels are used for power supply. The communication module of the network layer and the server of the cloud platform use the MQTT protocol to communicate, and the terminal regularly reports the collected data to the cloud platform, and the cloud platform can also issue instructions to proactively obtain data. The application layer is developed based on China Mobile's OneNET Internet of Things cloud platform, which collects status data from each line node for data storage, analysis, and OneNET view visualization processing. Both the visual interface and the background data console can issue commands for remote control of the acquisition terminal, realizing distributed monitoring and unified management of line vibration information. Figure 1 shows the structure of the monitoring system.

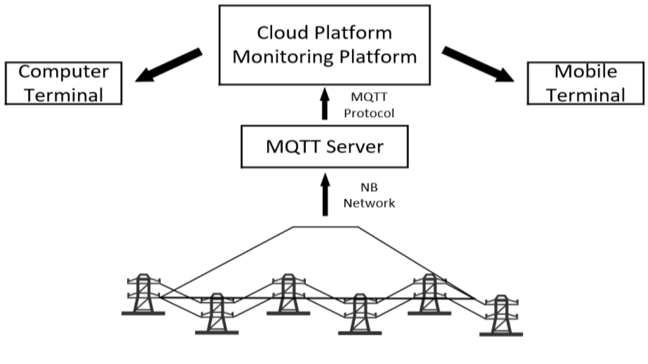



**Fig. 1.** Monitoring system structure diagram

## 3. Hardware design

The data acquisition board consists of the main control unit, acceleration sensor, NB module, temperature and humidity module, location module, storage module, and power module. The function of the acquisition board is to send the collected line vibration information and environmental information to the cloud platform for further processing by the NB module after processing by the main control MCU. The six-axis acceleration sensor, which is responsible for collecting the vibration information of the line, selects the GY-521 module with the MPU6050 chip as the core, integrates the three-axis gyroscope and three-axis accelerometer, and communicates with the main control MCU through the IIC interface. The small size of the module can significantly reduce the measurement errors caused by welding and embedding of the acquisition board. The main control chip adopts STM32F103C8T6 microcontroller, the core of the chip is ARM Cortex-M, which has the characteristics of high performance, low power consumption, real-time performance, high integration, and easy development, and can carry out complex data operation and data transmission. The temperature and humidity module adopts an AM2302 sensor, AM2302 humidity-sensitive capacitor digital temperature and humidity module is a temperature and humidity composite sensor with calibrated digital signal output. It uses dedicated digital module acquisition technology and temperature and humidity sensing technology to ensure high reliability and excellent long-term stability. The positioning module adopts the ATK-MO1218 module, which is a high-performance GPS/ Beidou dual-mode positioning module. The module adopts the S1216F8-BD module, which has the characteristics of small size and excellent performance. The module can be used to configure parameters through the serial port, and the configuration can be saved to the Flash memory, easy to use. The module is compatible with 3.3V and 5V communication levels, which is convenient for connecting various single-chip microcomputer control systems; The module comes with a rechargeable back battery, which can keep ephemeris data for about half an hour after the module power failure. With the warm or hot start of the module, rapid positioning can be achieved. The power module uses a 5V 2400mAh lithium battery with a 5.5V/1W solar panel hybrid power supply to ensure that the data acquisition board can work stably for a long time. AT24C04D using a Flash memory storage module, with the main control MCU via a serial port (serial peripheral interface, SPI) communication, is used to access and view the history state data. NB module adopts the BC26 module of Yuanyuan Company, which communicates with the main control chip STM32 through UART1 for reporting data to the cloud platform for real-time monitoring. Figure 2 shows the circuit schematic diagram of the BC26 module. The circuit design includes a RESET circuit, sleep mode circuit (PSM_ENT), and SIM card circuit. The RESET circuit is connected to the reset pin, and the sleep mode circuit is connected to the sleep-wake mode pin (PSM_ENT). When the module enters sleep mode, the networking activities will be closed, including cell message search, cell reselecting, etc., but the built-in T3412 timer in the BC26 module can still work. Enables BC26 to return to normal working mode when data needs to be transferred. The BC26 module connects to the SIM card through the reset interface (SIM_RST), data interface (SIM_DATA), and clock interface (SIM_CLK) to provide network services. The BC26 module has a number of spare pins (RESERVED) for secondary development. Figure 3 shows the hardware design structure of the data acquisition board. Figure 4 is the physical picture of the data acquisition board.

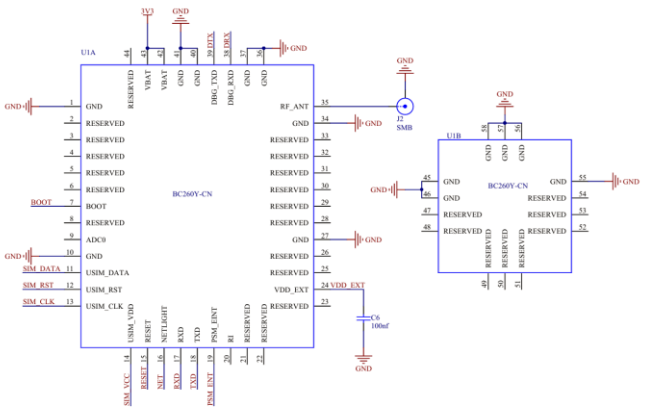


**Fig. 2.** Schematic diagram of BC26 module circuit

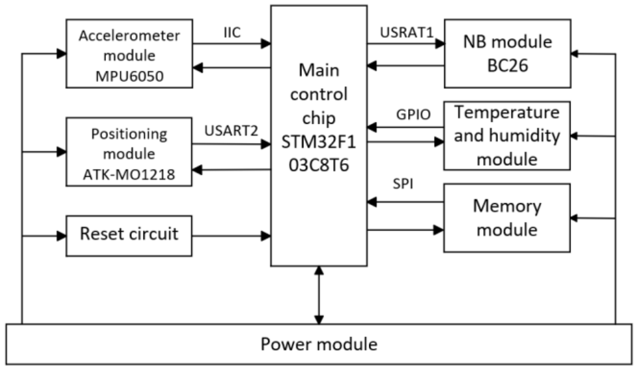



**Fig. 3.** Hardware design structure of data acquisition board

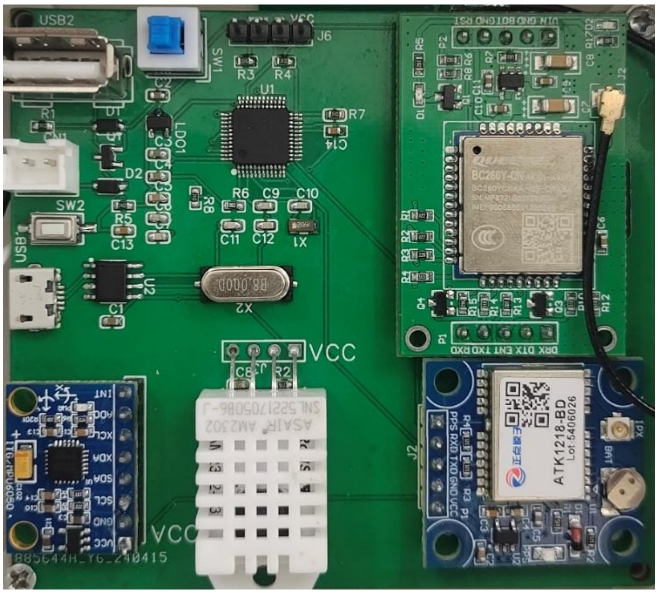


**Fig. 4.** Real picture of the data acquisition board

## 4. Software design

### *4.1 System Data Transmission Process*

The stability of network transmission determines whether the data can be transmitted to the cloud platform, and it is necessary to ensure that the line status data can be fully transmitted, and that the data acquisition device can respond to the instructions issued by the platform in time. To avoid the stopping of the acquisition terminal device caused by battery failure, the hardware devices on the line data acquisition board are mainly in hibernation state. The system reports data in two modes: periodic reporting by the terminal device and command acquisition by the platform. The design of the data transmission process for periodic reporting is shown in Figure 5. When the terminal device reports data periodically, the main control MCU will wake up each module and read each sensor data in turn. The MCU will filter the data through an algorithm, and then send the processed data to the NB module through the serial port to successfully send it to the cloud platform, and then control each module to enter the hibernation state. Wait for the next data report.

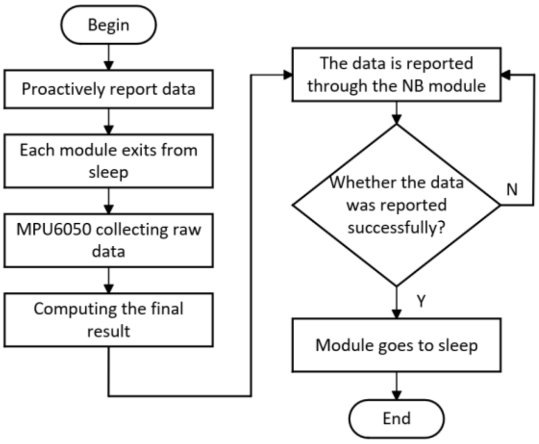



**Fig. 5.** Process of periodic data reporting

As shown in Figure 6, when the OneNET control center sends a data acquisition message, the NB module on the acquisition board will be awakened to accept the message from the platform and send the message to the main control MCU through USART1. After the MCU analyzes the message sent by the NB module, the main control MCU will wake up each module. After reading the data of each sensor in turn, the MCU filters the data through the algorithm and then sends the processed data to the NB module through the serial port to the cloud platform, the platform will feedback on whether the data is reported successfully. If it fails, it will report again at intervals, and control each module to enter the hibernation state after success.

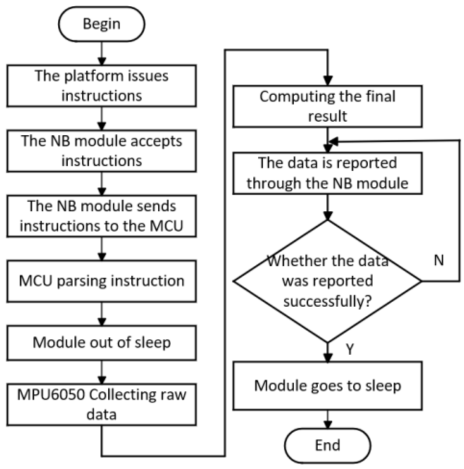



**Fig. 6.** Data acquisition process of the platform

### *4.2 NB-IoT wireless communication*

The NB-IoT module is responsible for reporting the data received from the main control MCU to the OneNET cloud platform and receiving related commands from the cloud platform. The cloud platform and BC26 module communicate through the MQTT protocol. If you want to establish a connection, you first need to create a product on the cloud platform, add the corresponding device under the product, and add the required data flow template. When establishing a connection, the BC26 module first needs to connect to the MQTT server of the cloud platform, and then log in to the device. After the successful login of the device, the device status of the platform will be displayed on the device interface. After the theme is published, the data that needs to be reported can be sent. After the data is successfully sent, the data console and display interface of the cloud platform will display the data that has just been uploaded. Figure 7 shows the data reporting process of the BC26 module.

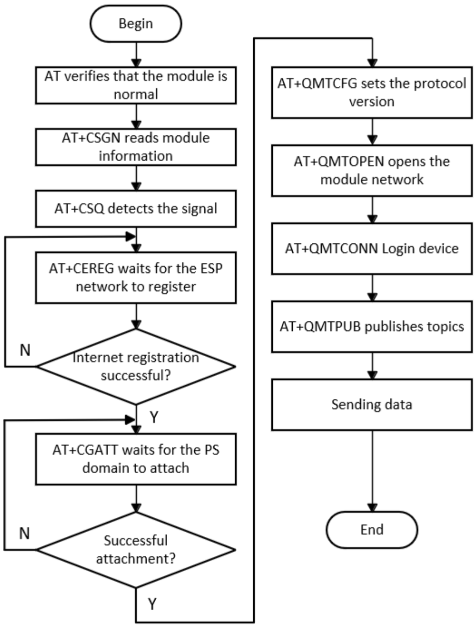



**Fig. 7.** BC26 module data reporting process

*4.3 Design of FFT algorithm based on wavelet noise reduction*

Transmission lines are subject to a variety of random excitation effects during operation, and their dynamic characteristics are complex, and the signals measured by sensors are easily affected by a variety of noises, including Gaussian white noise [7]. The main processing methods of breeze vibration signal include a least square method and the FFT method based on wavelet noise reduction.

*4.3.1 Least square method*

In this system, the wire breeze vibration signal is collected by the acceleration sensor. To obtain the displacement of the vibration signal, the integral and differential relationship among acceleration, velocity, and displacement can be used to obtain the transformation between the signals [8]. The amplitude of the vibration signal is obtained by converting the signal in the time domain and frequency domain. In the actual signal measurement, there is usually a small DC component, and the lag after integral processing often forms a trend term, and various noise signals will be mixed in the process of information acquisition. The least square method can be used to eliminate the trend term and filter processing to calibrate the signal. The principle is as follows:

Let the acceleration sampling data be $\{x_k\}\,(k = 1,2,3,\dots,n)$, sampling time interval $\Delta t = 1$ms, let the fitting polynomial function by:

$$x_k^{'} = b_0 + b_1 k + b_2 k^2 + \cdots + b_m k^m \tag{1}$$

Specify the coefficients $b_j (j = 1,2,3,\dots,m)$ to be determined in the function $x_k'$, thereby reducing the error between the function $x_k'$ and the discrete data $x_k$, so as to minimize the sum of its squares, that is, calculate:

$$E = \sum_{k=1}^{n} (x_k^{'} - x_k)^2 = \sum_{k=1}^{n} (\sum_{j=0}^{m} b_j k^j - x_k)^2 \tag{2}$$

The operation of the extreme value is expanded by using the bias derivative, where E must satisfy the following conditions:

$$\frac{\partial E}{\partial b_i} = 2\sum_{k=1}^{n} k^i (\sum_{j=0}^{m} b_j k^j - x_k) = 0 \tag{3}$$

In the above formula $i = 0,1,2,\dots,m$, the partial derivative of $b_i$ can form a linear system of (m+1) elements:

$$\sum_{k=1}^{n}\sum_{j=0}^{m} b_j k^{j+1} - \sum_{k=1}^{n} x_k k^j = 0 \tag{4}$$

Solving the above equations can obtain m+1 undetermined coefficients $b_j (j = 1,2,3,\dots,m)$ and then determine the fitting function.

The least square method was used to fit the acquisition signal curve with a vibration frequency of 10. The original signal and the processed results are shown in FIG. 8 and 9. The curve fitting by the least square method can effectively filter the trend term and noise signal caused by the DC component, but the data of 1 to 2 cycles must be intercepted by this method, otherwise, the fitting curve may be distorted.

Therefore, assuming that the least square method is used to fit the curve, it must be ensured that the original data used for fitting is the data within two cycles. After experimental research, it is concluded that when the signal is greater than 10Hz, the least square method needs to carry out a lot of logical operations, and the effect is not very good. When the signal is less than 10, the least square method is better. However, the transmission line breeze vibration mostly presents the characteristics of high frequency and low amplitude, so it is not suitable to analyze the transmission line breeze vibration signal by the least square method.

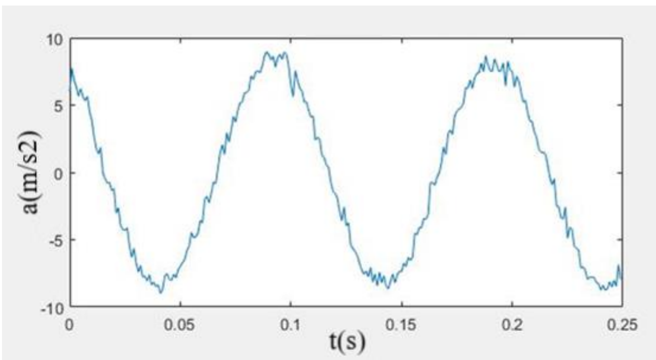



**Fig. 8.** 10Hz signal original curve

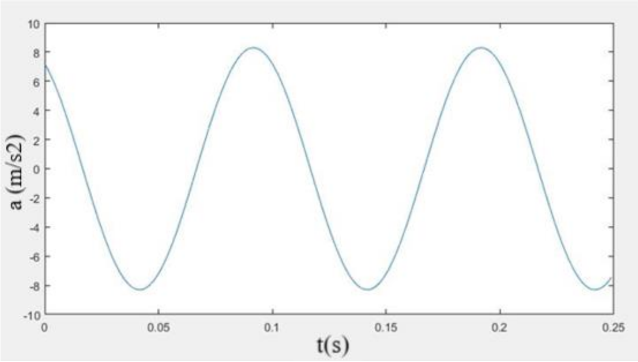



**Fig. 9.** 10Hz signal least square fitting curve

*4.3.2 FFT based on wavelet noise reduction*

Wavelet analysis is a kind of time-frequency analysis, which is a great breakthrough in Fourier analysis research methods. Wavelet transform is a mathematical method to uses the local idea of Fourier transform and then expands the space-time series analysis of it [9].

If $\Psi \in L^2(R)$ meet the conditions of $\int \Psi(t)dt = 0$, says $\Psi$ is a base wavelet, otherwise known as the mother wavelet, the signal of $x(t)$ can be represented as continuous wavelet transform

$$WT_X(a,b) = a^{-\frac{1}{2}}\int_{-\infty}^{+\infty} x(t)\bar{\psi}(\frac{t-b}{a})dt =< x(t),\psi_{a,b}(t) > \quad (5)$$

$$\psi_{a,b}(t) = a^{-\frac{1}{2}}\psi\left[\frac{t-b}{a}\right] \quad (6)$$

Where: $a, b \in R$, where a is the scale factor corresponding to the same frequency variable, while b is the displacement factor corresponding to the same time variable. $\Psi_{a,b}(t)$ represents the family of wavelet functions formed based on wavelet translation and scaling, also known as wavelet basis function.

Suppose $\Psi \in L^2(R)$ to reconstruct condition $C_\Psi = \int_R \frac{|\Psi(W)|^2}{W} dw < +\infty$ , then you can get a signal wavelet reconstruction formula:

$$x(t) = C_{\psi}^{-1}\int_R\int \psi_{a,b}(t)WT_X(a,b)db\frac{da}{a^2} \quad (7)$$

The scale factor a and the displacement factor b are discretized, and then the discrete wavelet transform is obtained. In $\Psi_{a,b}(t)$, the man function of scale factor a is to expand and scale the fundamental wavelet. The displacement factor b expands and moves it on the time level to obtain the time position resolved by $x(t)$. $\Psi(t)$ replaced by $\Psi(t/a)$, assuming a more than 1, so if its value is larger, so $\Psi(t/a)$ in the time domain is wider; Suppose that the smaller a is, then the narrower the time domain of $\Psi(t/a)$. Thus, the signal $x(t)$ can be processed using a set of wavelets with continuously varying widths. When the frequency range is different, the resolution will also be different. In detail, the analysis window in the wavelet transform can automatically change, and for the resolution, its performance is poor in the high-frequency range, but the resolution in the time domain is excellent; At low frequencies, on the contrary, the time domain resolution is poor, but the frequency resolution is excellent. If the value changes, then the time-frequency resolution will change with it. Generally speaking, in the vibration signal, the opposite of the high frequency is the unsteady part of the signal, but in the low-frequency part, it corresponds to the steady state part of the signal. For the high-frequency part, the requirement of time domain resolution is higher, but the requirement of the frequency domain is lower. In the low-frequency part, it is just the opposite, which shows the advantage of the time-frequency locality of the wavelet transform.

There is no information loss in the process of wavelet transform, which can ensure the effectiveness of signal analysis, and is a powerful signal transformation and analysis tool.

The principle of wavelet denoising is as follows: Suppose that a noisy signal is:

$$s(t) = f(t) + e(t) \quad (8)$$

In the above formula, f(t) represents the original signal, e(t) is the noise signal, and s(t) is the signal containing noise. The noisy signal is decomposed by wavelet so that most of the noisy signal can be decomposed into the high-frequency band, to achieve noise reduction.

Given the excellent frequency resolution characteristics of Fourier transform and time-frequency analysis characteristics of wavelet transform, this project chooses the FFT method based on wavelet noise reduction as the processing method of vibration signal: Firstly, db10 wavelet is used to decompose the signal by 3-layer discrete wavelet to remove the interference signals such as steady-state component and white noise from the original signal, and then Fourier transform is used to analyze the frequency spectrum of the reconstructed signal to obtain the vibration information of the transmission line.

FIG. 10 is the curve drawn by the acceleration sampling value when the vibration signal is 30Hz and 0.2mm. The 30Hz vibration signal in FIG. 10 is transformed by a discrete wavelet, and the time-domain waveform of each layer is shown in FIG. 11.

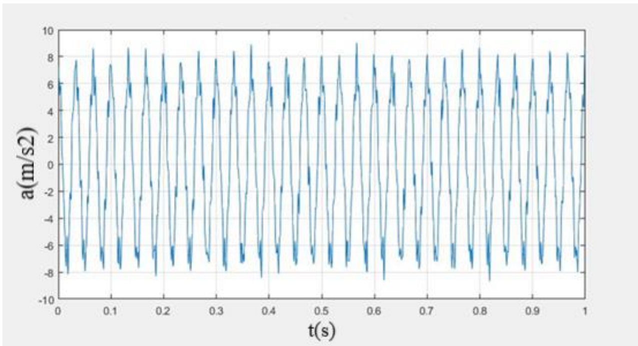
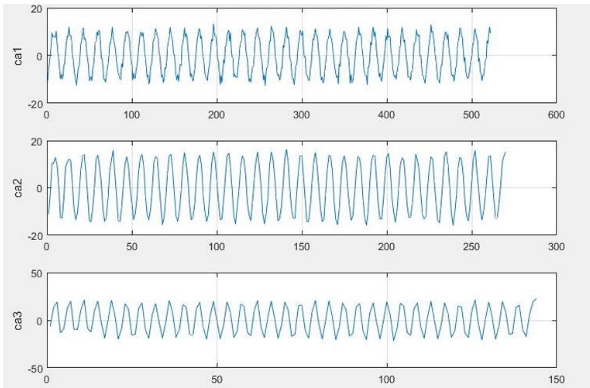
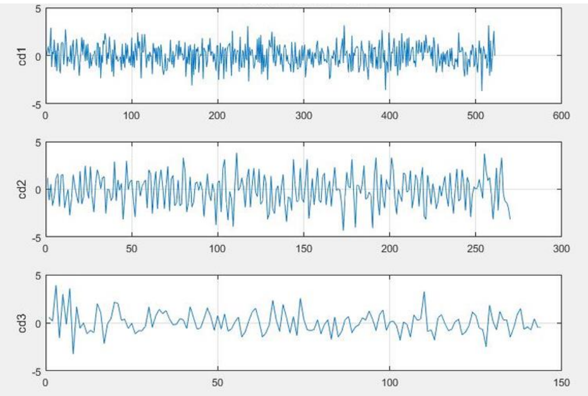



**Fig. 10.** 30Hz signal acceleration curve




(a) Low frequency




(b) high-frequency

**Fig. 11.** Low frequency and high-frequency coefficients of each layer decomposition of the original signal wavelet

The original signal was denoised by a soft threshold wavelet, and the waveform after denoising was obtained. Figure 12 shows the comparison between the original signal and the denoised signal. The signal after noise reduction is similar to the original signal, which retains the useful part of the signal and eliminates the interference. The spectrum diagram of the denoised signal can be obtained by FFT, as shown in Figure 13. It can be seen intuitively from the spectrum diagram that after the signal is reduced by wavelet decomposition, the interference of high-order harmonics and noise signals is filtered out, especially the noise reduction effect of white noise is particularly obvious, which provides more accurate pre-processing data for vibration signal analysis.

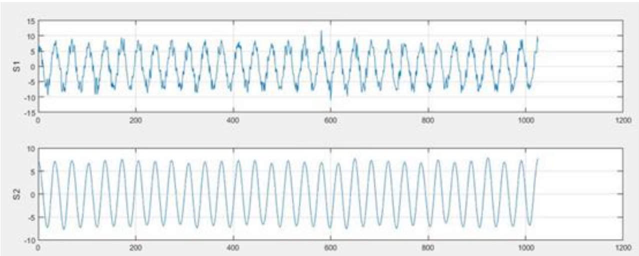



**Fig. 12.** The original signal and the signal after noise reduction

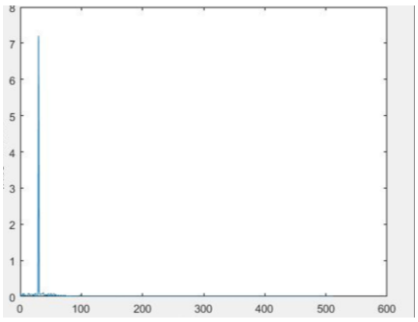


**Fig. 13.** Spectrum diagram of signal after noise reduction

The accuracy of vibration signal detection directly affects the fatigue damage assessment of wire and the implementation of anti-vibration measures. Wavelet soft threshold denoising is used to reduce the noise of the wind vibration acceleration signal, and the denoised signal is analyzed by a fast Fourier transform. The reconstructed signal after wavelet de-noising is closer to the original signal, and the de-noising method improves the accuracy of vibration signal detection. This method combined with wavelet de-noising and FFT is suitable for application in the breeze vibration monitoring system.

## 5. Monitoring system cloud platform design

Considering the development cost, reliability, system scalability, and spatial data model expansion of the big data platform, the platform should be stable in the later expansion and upgrade. The system adopts the China Mobile OneNET Internet of Things cloud platform based on the MQTT lightweight Internet of Things protocol. MQTT supports the TLV/JSON/Plaintext/Opaque data formats, and provides a lightweight compact safety communication interface and highly efficient data model, to meet the requirements of the monitoring system. The cloud platform of vibration monitoring system mainly realizes:

(1) Build a monitoring service. When the acquisition board wants to obtain data during the period when it does not report data, it sends instructions to the acquisition board to obtain monitoring data for specified nodes. After that, the vibration data is analyzed and stored in the SQL database of the cloud platform for subsequent use.

(2) The cloud platform needs to respond to the user request of the mobile end in time. If it is a request for obtaining vibration state data, it only needs to send the historical data in the database to the mobile end. If it is a control command, the cloud platform needs to forward the command to the data acquisition board for further processing to achieve the control effect.

## 6. System test

When predicting the vibration or strand breakage of a high-voltage transmission line, the test time is one day in strict accordance with the national standard power information security specifications. Due to the influence of strong winds, the vibration amplitude of the safe operation of the line is up to 0.6mm. When the vibration data of the transmission line exceeds this value, the monitoring system will determine that the line has a safety hazard or even strand breakage. At this time, the display interface will display alarm, and vibration mark position 1. The monitoring display interface has a weather window, you can view the weather conditions of the day and the next few days, if the wind exceeds 5 on the day, it will also alarm. When the sensor does not work properly, the working status is set to 0. When monitoring the vibration state of the line, a data acquisition board is deployed at the node of the transmission line to collect vibration data every 10 minutes, and the data within a certain period of the day is selected for observation, as shown in Table 1.

**Tab. 1.** Transmission line vibration state data table

| Serial number | The amplitude of line vibration /(mm) | Wind force | Working condition | Alarm flag bit |
|---|---|---|---|---|
| 1 | 0.18 | 2 | 1 | 0 |
| 2 | 0.23 | 3 | 1 | 0 |
| 3 | 0.1 | 1 | 1 | 0 |
| 4 | 0.26 | 3 | 1 | 0 |
| 5 | 0.6 | 6 | 1 | 1 |
| 6 | 0.3 | 4 | 1 | 0 |
| 7 | 0.16 | 2 | 1 | 0 |
| 8 | 0.24 | 3 | 1 | 0 |
| 9 | 0.1 | 1 | 0 | 0 |

## 7. Summary

A new line breeze vibration monitoring system based on an NB-IoT communication module is designed, which can monitor the vibration state of the transmission line in real-time. This system uses a MEMS accelerometer to collect vibration state data of high-voltage transmission lines. By introducing an FFT algorithm based on wavelet noise reduction, the noise reduction capability of the MEMS accelerometer is effectively improved. Narrowband Internet of Things wireless communication technology is used to realize information exchange between high-voltage transmission line nodes and cloud platforms. The system realizes the online monitoring of the high-voltage transmission line of the power system and can alarm according to the vibration degree of the line, which changes the status quo that the existing technology can not effectively monitor in real, and provides an effective solution for protecting the safe operation of the power system.

## Acknowledgements

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***Jie Sun*** obtained his master's degree in Electrical Engineering and Automation Engineering from Northeast Electric Power University in 2008. The current State grid Heilongjiang Electric Power Co., LTD Qiqihar power supply company science and technology digitalization department is responsible for science and technology. His research interest is electric power automation.
E-mail: 1443345723@qq.com

***Hao Li*** graduated from Northeast Electric Power University in 2012, majoring in Electrical Engineering and Automation. Current State Grid Heilongjiang Electric Power Co., LTD Qiqihar power supply company substation maintenance center director. His research interests include transmission line operation and maintenance, substation operation and maintenance, and high voltage test.
E-mail: 375200786@qq.com

***Xinbo Sun***, studying in China Three Gorges University, majoring in civil engineering, mainly focuses on the construction of power system civil engineering.
E-mail: lysuny@163.com

***Jitao Li*** received his master's degree in Engineering management from Harbin University of Science and Technology in 2019. The current State grid Heilongjiang Electric Power Co., LTD Qiqihar power supply company operation maintenance department deputy director. His main research interest is smart grid.
E-mail: grant3720391@126.com