NB-IoT based method for monitoring the tilt status of transmission towers

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Abstract. The current monitoring of transmission tower tilt status mainly uses a combination of manual and sensor data collection, which not only has low monitoring efficiency and high cost, but also makes it difficult to guarantee the monitoring accuracy. In response to the problems of the above research, the NB-IoT-based transmission pole tower tilt state monitoring method will be studied. Six-axis attitude sensor GY-521, wind sensor and tension sensor are used to collect the pole tower status data. The NB-IoT network is designed to transmit the noise reduction processed data to the base station, which is transmitted to the upper computer. The data is analyzed in the upper computer using LSTM network to get the monitoring results of the tilt status of the pole tower. The experimental results show that the maximum root mean square error of the proposed monitoring method is only 0.02701, which is much smaller than the comparison method, and the monitoring efficiency is high and the performance is more suitable for practical applications.

1. Introduction
In the natural environment and the role of external conditions, tower foundation from time to time will occur slip, tilt, settlement, cracking and other phenomena, thus causing the deformation of the tower, tower tilt or even inverted tower break line tower tilt will cause the tower guide ground line unbalanced force, causing the tower force changes, resulting in electrical safety distance is not enough, affecting the normal operation of the line. Inverted tower line will make the power supply line in paralysis, seriously affect people's production life, causing huge losses [1]. Therefore, in the daily maintenance of power system, we need to focus on the monitoring and management of transmission equipment, especially the transmission tower state. In the early days, the monitoring of the status of transmission towers by relying on manual patrol inspection not only required high technical level of inspectors, but also had cumbersome inspection steps and extremely low monitoring efficiency[2]. Non-destructive monitoring of transmission towers using ultrasonic pulse velocity in transmission towers in different states, although it reduces the cost investment of manual monitoring, but it cannot evaluate the tower tilt state from the perspective of data, and there are limitations in its use [3]. Nan Yinggang et al. used fiber-optic grating stress sensors to collect the stress changes in towers under wind and ice loads, so as to build a finite element model of the tower to achieve monitoring of the tilt state of the tower. This method only takes into account the influence of a limited number of factors on the tower tilt, which is only applicable to the monitoring of tower tilt in some areas and is not universally applicable [4].

In recent years, many experts and scholars at home and abroad have studied the characteristics of NB-IoT that are different from other wireless communication technologies and optimized its shortcomings in the current stage [5]. The NB-IoT data can be directly connected to the official
platform of telecom operators, which is more convenient for development and practical management. In this paper, NB-IoT technology is applied to monitoring the tilt status of transmission towers, and a set of sensor-based transmission tower tilt detection method is designed to obtain and analyze and upload transmission tower tilt status information.

2. NB-IoT based method for monitoring the tilt status of transmission towers

2.1. Transmission tower tilt status data collection

Tilt angle of transmission tower is an important parameter to measure the state of the tower, use at the top of the column of angle sensor installed in the transmission tower, tower angle and the mathematical relationship between the sensor output, the specific size of the transmission tower angle can be calculated. In this study, a 6-axis attitude sensor GY-521 is selected for the transmission tower tilt angle measurement [6], which uses an MPU6050 acceleration sensing chip to digitally output the 6-axis rotation matrix data of the fusion algorithm, which solves the problem of inter-axis difference compared to other multi-component combination sensors. Table 1 below shows the performance parameter table of MPU6050.

| Number | Performance Parameters  | Specific values                  |
|--------|-------------------------|----------------------------------|
| 1      | currents                | 3-6V                             |
| 2      | current                 | <10m A                           |
| 3      | range (of scales or measuring equipment) | Acceleration: ±16g  |
| 4      | measurement dimension   | Acceleration: 3°/S  |
| 5      | Data output frequency   | 100HZ (baud rate 115200).  |
| 6      | baud rate               | 115200                           |
| 7      | stability               | 9600                             |
| 8      | Stability of attitude measurement resolution (of a photo) | Acceleration: 0.01°  |
| 9      |                         | Acceleration: 6.1e-5g            |

When the transmission tower is in a tilted state, the gravitational acceleration of the tower has components on all three axes, and these components are combined to be the gravitational acceleration [7], using trigonometric functions to calculate the angle at which an axis deviates from its original position (start by putting the tilt sensor as close to the original position as possible for reference). FIG. 1 below shows the relationship between acceleration and inclination angle for the three axes.
Fig. 1 Relationship between triaxial acceleration and inclination angle

From FIG.1, the calculation formula of inclination angle can be deduced:

\[ \alpha = \tan^{-1} \left( \frac{A_x}{\sqrt{A_y^2 + A_z^2}} \right) \]  \hspace{1cm} (1) \hspace{1cm} \beta = \tan^{-1} \left( \frac{A_y}{\sqrt{A_x^2 + A_z^2}} \right) \]  \hspace{1cm} (2) \hspace{1cm} \gamma = \tan^{-1} \left( \frac{\sqrt{A_x^2 + A_y^2}}{A_z} \right) \]  \hspace{1cm} (3)

In the above formula, \( \alpha \), \( \beta \) and \( \gamma \) are the deviation angles corresponding to the X, y and Z axes of the triaxial acceleration respectively. Since the sensor is installed at the cross arm of the tower top and the waist of the tower, ignoring the influence of the tower material deformation of the tower itself, in the actual measurement[8], only the gravity acceleration changes in the x-axis and Y-axis directions need to be collected, that is, the along-line tilt angle and the transverse tilt angle of the tower. To improve the efficiency of monitoring of transmission tower tilted state, this study uses NB-IoT network transmission sensor acquisition of transmission tower tilted state data.

2.2. NB-IoT Network Design

In the network architecture of NB-IoT, it includes: NB-IoT terminal, E-UTRAN base station, home subscriber server (HSS), mobility management entity (MME), service gateway (S-GW) and PDN gateway (P-GW); service capability exposure function (SCEF) [9]. The Service Capability Open Unit SCEF and the corresponding interfaces T6 and S6t are used for non-IP data transfer. Among them, T6 interface is used to connect SCEF and MME; S6t interface, to connect SCEF and HSS. The NB-IoT network architecture for pole tower tilt status monitoring is shown in FIG. 2.

![NB-IoT network architecture diagram](image)

The NB-IoT communication network acts as a bridge in the whole monitoring process, connecting measurement units such as gyroscopes, accelerometers and attitude sensors at the bottom layer and data processing center at the top layer. The bottom sensor network is connected to the NB-IoT network to provide monitoring data for the tilt status of transmission towers. The NB-IoT network has two power saving modes to reduce the operating power consumption of hardware devices. In this study, the NB-IoT network is selected to operate in eDRX mode in order to meet the real-time...
monitoring of the tilt status of transmission poles. In eDRX mode, a TAU cycle consists of two state cycles, Connect eDRX and Idle eDRX. In Connect eDRX, it is necessary to listen to the PDCCH and receive downlink data with a maximum receive cycle of 10.24s. The communication protocol of each terminal in NB-IoT network is COAP communication protocol. CoAP restricted application protocol is mainly used in IoT scenario. CoAP protocol is a one-to-one protocol to achieve communication between terminals and servers.

2.3. Transmission tower tilt state data processing
The two filters give an all-pass estimate of the tilt angle, and the complementary filter model is simple enough to provide accurate tilt angle data over a wide frequency band. The complementary filter based tilt angle sensor data fusion method can have the advantages of both accelerometer and gyroscope. The mathematical model of the complementary filter is described as follows.

\[ \theta_a = \eta \times (\theta_a + \omega \times \Delta t) + (1 - \eta) \times \theta_{acc} \quad (4) \]

Where, \( \theta_a \) is the inclination angle; \( \eta \) is the complementary filter factor; \( \omega \) is the angular velocity measured by the gyroscope. The tilt angle of the transmission tower measured by the accelerometer is \( \theta_{acc} \). The magnitude of the time constant \( \tau \ (\tau \in [0,1]) \). Suppose the sampling interval of the sensor is \( \Delta t \) when the sensor collects transmission towers, then the time constant for the filtering process by the complementary filter is defined as:

\[ \tau = \frac{\eta \Delta t}{1 - \eta} \leftrightarrow \eta = \frac{\tau}{\tau + \Delta t} \quad (5) \]

After processing the transmission tower tilt status monitoring data collected by the sensors according to the above, the data is transmitted via the NB-IoT network base station to the upper computer for analysis, and the LSTM neural network is used to realize transmission tower tilt status monitoring.

2.4. Implementing transmission tower tilt condition monitoring
The repetitive hidden layer module of the LSTM neural network has three gate controllers and a memory unit. The three gate controllers are the input gate, the forgetting gate and the output gate. The gate controllers mainly include the Sigmoid function and the dot product operation. The input vector of the input gate at the time \( t \) is:

\[ a_t = U_t \times s_{t-1} + W_t \times x_t + b_t \quad (6) \]

Where, at time \( t \), when the LSTM network is processing the sensor data, the input vector of the input gate is \( a_t \); \( s_{t-1} \) is the output vector of the hidden layer at \( t-1 \); when the LSTM network is processing sensor data at time \( t \), the input vector of the network as a whole is \( x_t \). \( W_t \) is the weight matrix between the input gate and the neural network input layer. \( U_t \) is the weight matrix between the input gate and the LSTM hidden layer at the previous moment; \( b_t \) is the offset of the input gate. The input vector of the output gate at the time \( t \) is:

\[ a_t = U_o \times s_{t-1} + W_o \times x_t + b_o \quad (7) \]

Where, at time \( t \), when the LSTM network is processing the sensor data, the output \( t \) vector of the input gate is \( a_t \); \( W_o \) is the weight matrix between the output gate and the neural network input layer; \( U_o \) is the weight matrix between the output gate and the LSTM hidden layer at the previous moment; \( b_o \) is the offset of the output gate. The output vector of the output gate at time \( t \) is:

\[ g_t = f_o (a_t) \quad (8) \]
Where, $g_t$ is the output vector of the output gate at time $t$; $f_o(\ )$ is the sigmoid function. The input of the implicit layer of the LSTM consists of the input vector and the output of the implicit layer at the previous moment, and the function is hyperbolic tangent function. The tower tilt data collected by each sensor when stationary and different external forces are applied to the transmission towers are selected as the training data of the LSTM network.

3. Experimental studies

3.1. Experimental data and preparation

In this paper, a wineglass tower in a 110 kV transmission line of a regional power grid is selected for study and analysis. The transmission line pole tower meets the normal environmental requirements for line ice cover load, construction conditions, and wind load. The towers have a tower height of 34.8 m, a call height of 29.8 m, and a root opening of 5.77 m. The towers at different locations in the line were selected as the study objects, and the corresponding sensors were installed and sensor communication networks were formed according to the design requirements of the two monitoring methods. According to the data of meteorological department, the tilt state of the pole tower is monitored under different winds with the influence factor of wind on the tilt of the pole tower. The modeling analysis results of the simulation software are used as standard values to calculate the monitoring errors of the two monitoring methods. The monitoring time of the two monitoring methods during the detection process is also counted.

3.2. Experimental results and analysis

Table 2 below shows a comparison of the monitoring results of the two transmission tower tilt monitoring methods.

| Wind Power Rating | Distance to data base station/m | NB-IoT monitoring methods | RTK monitoring methods |
|-------------------|--------------------------------|---------------------------|------------------------|
|                   | Monitoring mean squared error MSE | Average monitoring time/ms | Monitoring mean squared error MSE | Average monitoring time/ms |
| 4                 | 100                             | 0.02654                   | 14.1                   | 0.03564                   | 18.2                   |
| 4                 | 300                             | 0.02698                   | 15.9                   | 0.03789                   | 20.6                   |
| 5                 | 100                             | 0.02661                   | 14.6                   | 0.03691                   | 19.4                   |
| 5                 | 150                             | 0.02634                   | 15.2                   | 0.04135                   | 21.9                   |
| 6                 | 100                             | 0.02667                   | 15.7                   | 0.04277                   | 22.5                   |
| 6                 | 200                             | 0.02701                   | 15.3                   | 0.04563                   | 26.7                   |

From the data in table 2 above, it can be seen that the maximum root mean square error of monitoring the tilt state of transmission towers by the monitoring method in this paper is only 0.02701, which is smaller than the root mean square error of the RTK monitoring method. Moreover, the average monitoring time of the method in this paper fluctuates very little under the influence of different levels of wind, while the average monitoring time of the RTK monitoring method has more obvious fluctuations. In addition, from the data in table 2 above, it can be seen that the monitoring efficiency and accuracy of the RTK monitoring method are more obviously affected by the distance of the monitoring object.

4. Conclusion

Transmission tower tilt can lead to abnormal electricity network system, and severe can lead to a crash, it will eventually result in serious economic loss and serious safety accidents. By monitoring the basic condition of the transmission tower, it is of certain significance to reduce the occurrence of accidents
and economic losses. In order to improve the accuracy of transmission tower state monitoring and to avoid the transmission tower lean phenomenon, affecting the safety of transmission and personnel work in this paper, we study the transmission tower tilt condition monitoring method based on NB-IoT. Using NB-IoT technology of high-speed communication performance, this method improves the transmission tower tilted condition monitoring accuracy and efficiency. In the future, in-depth research will be carried out on tower condition monitoring in different environments, with the help of a variety of sensors and sensor data fusion algorithms, so as to improve the universal applicability of transmission tower inclination monitoring methods.

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