The Research and Implementation Transmission Line Tower Rod and Monitoring System Using Reverse Network RTK Technology

Yi Jin\textsuperscript{1,a}, Wei Wang\textsuperscript{2,b}, Ling Pei\textsuperscript{3,c}, Xin Chen\textsuperscript{4,d}, Bao Song\textsuperscript{5,e}

\textsuperscript{1}State Grid Shanghai Municipal Electric Power Company, NO.1122 Yuanshen RD Pudong New District, Shanghai, China +86 021-28925222

\textsuperscript{2}State Grid Shanghai Municipal Electric Power Company, NO.1122 Yuanshen RD Pudong New District, Shanghai, China +86 021-28925222

\textsuperscript{3}Shanghai Key Laboratory of Navigation and Location-based Services, Shanghai Jiao Tong University, NO.800 Dongchuang RD, Minhang District, Shanghai, China +86 021-34207446

\textsuperscript{4}Shanghai Key Laboratory of Navigation and Location-based Services, Shanghai Jiao Tong University, NO.800 Dongchuang RD Minhang District, Shanghai, China +86 021-34207446

\textsuperscript{5}School of Geomatics, Anhui University of Science and Technology, NO.168 Taifeng ST Shannan New District, Huannan, China +86 17855477570

\textsuperscript{a}jinyi1002@163.com, \textsuperscript{b}ling.pei@sjtu.edu.cn, \textsuperscript{d}xin.chen@sjtu.edu.cn, \textsuperscript{e}bsong20@126.com

Abstract. In order to solve the problems of low monitoring accuracy, high false alarm rate, untimely pre-warning and high equipment failure rate of the transmission line tower rod oblique posture monitoring system, a transmission line tower rod oblique monitoring system based on reverse network RTK was developed. The system integrated the Beidou multi-source sensor, network communication and prediction and forewarning, used the height and millimeter level position information of the transmission line tower to measure and calculate oblique posture information of the tower pole, and made risk assessments, so as to realize the control of these information. The actual tests results showed that the monitoring system could accurately obtain the oblique posture information of the transmission line tower pole, and the pre- alarming monitoring results met the requirements of intelligent, accurate and digital management of transmission line tower pole.

1. INTRODUCTION

The Power tube pole is a kind of important facility to carry the power supply. Its fault-free operation is of great significance to ensure industrial development, resident life along the line, traffic safety, etc [1,2]. At present, there are two main ways of power tube pole monitoring: one is the combination of manpower inspection and wired communication while the other is the remote monitoring system based on wireless sensor. Wherein, the former requires large manpower and material investment, has low efficiency and is easy to be affected by the external environment; while the remote monitoring system based on the wireless sensor can realize on-line prediction of tower pole oblique state and external
environment parameters in special areas of transmission lines, and provide forewarning information of the oblique tower pole combined with the line design parameters, which make the operation department understand safety in time, reduce accidents caused by oblique tower pole, and assist the operation department to quickly find fault points. In view of these advantages, it is rapidly extended. However, affected by the installation of sensors, this way can result in lower monitoring accuracy, higher false alarm rate and high failure rate of equipment [3,4,5,6,7,8]. To solve problems above and improve the reliability and accuracy of tour inspection, this paper adopts reverse network RTK positioning algorithm to design a transmission line tower rod oblique monitoring system integrating Beidou multi-source sensor, network communication and prediction and forewarning.

2. THE MONITORING SYSTEM

2.1. The Platform Design

The real-time monitoring and forewarning system of transmission line tower rod is based on Beidou reverse network RTK high-precision phase difference positioning technology. It measures the real-time position of the antenna through collecting tower rod integration and then resolve the precise position of the antenna in real time combined with the positioning error provided by Beidou base station [10,13,14]. The monitoring system calculates the antenna real-time displacement, the oblique angle and the verticality of the steel tower according to the high-precision coordinates, and monitors the wind speed and direction, temperature, humidity and other information of steel tower in the current environment through reliable non-mechanical meteorological station. Then, the monitoring data is transmitted to the cloud platform through the wireless communication system, so as to complete alarm display, data storage, historical inquiry, etc. Working principle diagram is shown in Fig. 1.

![Figure 1 The working principle diagram of the system.](image)

The monitoring and forewarning system mainly consists of a monitoring subsystem, a base station subsystem and a data center software. The overall structural diagram is shown in Fig. 2. The monitoring subsystem transmits the Beidou observation data to the data center, the base station subsystem obtains the difference correction data in real time, and the data center subsystem stores, processes, calculates with model, analyzes and forewarns the observation data from the reference station and the monitoring station [3].
As the core of the whole system, the data center subsystem is composed of engineering management module, data analysis module, network communication module, reverse network RTK positioning algorithm module, coordinate conversion module, data storage module, graphic analysis module, disaster forewarning module, file download module and others. The composition diagram of each module in software is shown in Fig. 3.

2.2. The Key Algorithm

2.2.1. The Reverse Network RTK Technology

The Reverse network RTK technology was put forth by Dr. Chris Rizos of Australia in 2007. Basically, the same as the positioning algorithm flow of conventional network RTK, both used the observation data from base and moving stations to group double difference observation equation, and then resolve the location [9]. The data processing of its positioning algorithm is shown in Fig. 4. The differences are the differential data format generated by reverse network RTK technology and the evaluation criteria for positioning accuracy and quality of the observation data in the base and moving station in the data...
Reverse network RTK technology not only reduces the limitation of equipment’s own conditions and the influence of the environment, but also ensures the accuracy and reliability of the positioning result data, and can realize the high-precision positioning of single-frequency receiver [9].

![Figure 4: The principle flow chart of RTK of Beidou reverse network.](image)

**2.2.2. The Transmission Line Pole Tilt Model**

The calculation formula of tower oblique angle is mainly calculated in combination with the following figure [5,6,7,8]:

![Figure 5: The relationship diagram of oblique angle, tower height and plane displacement of the steel tower.](image)
(1) The initial value coordinate of Beidou positioning data measurement is \( (X_0, Y_0, H_0) \) and the coordinate of real-time measurement is \( (X_i, Y_i, H_i) \). The real-time displacement of the top of the communication base station (steel tower) is:

\[
\Delta P = \sqrt{\Delta X^2 + \Delta Y^2} \tag{1}
\]

Wherein, \( \Delta X \) and \( \Delta Y \) are the positioning deviation in the x and y directions respectively, while \( \Delta X = X_i - X_0, \Delta Y = Y_i - Y_0 \).

The root mean square error calculation formulas of the positioning result in x, y, and p directions are:

\[
\begin{align*}
X_{RMS} &= \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1}} \\
Y_{RMS} &= \sqrt{\frac{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}{n-1}} \\
P_{RMS} &= \sqrt{\frac{\sum_{i=1}^{n}(P_i - \bar{P})^2}{n-1}}
\end{align*} \tag{2}
\]

Wherein, the total observation number is \( n \), the average of the observation values in the x, y, and p directions are \( \bar{X}, \bar{Y} \) and \( \bar{P} \) respectively.

(2) The distance from the Beidou positioning antenna installed above the communication base station (steel tower) to the bottom of the steel tower is \( H \), the oblique angle is \( \theta \), then the calculation formula is:

\[
\theta = \arcsin \frac{\Delta P}{H} \tag{3}
\]

Where \( \Delta P \) represents the plane displacement difference of tower tilt Angle; \( H \) represents tower height.

3. Experiment

3.1. Normal or Body Text

A tower pole in Pukou District of Nanjing was selected for the monitoring experiment. The site and receiver are shown in Fig. 6. The study object is the RTK positioning data on October 23, 2019. The sampling rate is 1 second. The average value of data per minute is taken as the basic unit, with a total number of \( 24 \times 60 = 1440 \). The average value of the tower rod of previous whole day without interference is taken as the reference value, which is referred to hereafter simply as true value. Fig. 7 is the deviation result of positioning in the x, y, and p directions from the true value of the tower receiver phase center.

![Figure 6](image_url) The physical picture of an iron tower and receiver in Nanjing.
Figure 7(a). The positioning deviation in the x direction.

Figure 7(b). The positioning deviation in the y direction.

Figure 7(c). The positioning deviation in the p direction.

The error statistics results from Fig. 7 are shown in table 1. The standard deviation of XYP results is in mm level, the standard deviation of X direction is 2.75mm, the standard deviation of Y direction is 2.83mm, and the standard deviation of P direction is 2.51mm.
| Error                        | X(cm) | Y(mm) | P(mm) |
|------------------------------|-------|-------|-------|
| Mean square error            | 0.275 | 0.283 | 0.251 |
| Maximal deviation            | 1.85  | 1.62  | 2.1   |

**Fig. 8** is the tilt angle value of the Tower Pole at the measuring position. It can be seen that the tilt angle of the Tower Pole is between 0’ and 2.5’ in the above-mentioned environment, the fluctuation range is extremely small, and the standard deviation of the tilt angle is 0.375’, which meets the requirements of the power tower pole for the accuracy of tilt measurement. In addition, according to the meteorological data, it can be seen that the tilt Angle of the tower pole changes with the change of time and wind environment, and there is an obvious space-time continuity, which can be popularized to measure the Angle of the power tower pole.

![Figure 8](image_url)

**Figure 8** The tower pole Angle at the measuring point.

4. CONCLUSION

The improved transmission line tower rod oblique monitoring and pre-warning system based on Beidou/GNSS reverse network RTK reached millimeter-level positioning accuracy through the reverse network RTK high-precision phase difference algorithm, calculated the difference between the current position and the base position of the receiver antenna in the same coordinate system, and then get the real-time displacement of relative base place on the current position. Finally, the oblique angle was got using the system oblique angle algorithm. Through verification, the output accuracy of each value (the median error in x direction is 2.75 mm, in the Y direction is 2.83 mm, and in the plane p direction is 2.51 mm. The oblique angle is less than 2.5’) all met the requirements of design and railway standards.

The improved automatic monitoring system equipment of transmission line tower rod based on Beidou/GNSS reverse network RTK eliminated the influence of traditional monitoring technology ground environment on tower monitoring accuracy, and improved the reliability and real-time performance of monitoring data. It has broad application prospects in the field of railway transportation, public network communication steel tower (Mobile, Unicom, Telecom, etc.), electric steel tower monitoring, high-rise cultural relics building monitoring, modern high-rise building oblique monitoring and other related fields. Meanwhile, as a domestic satellite navigation and positioning System, Beidou system has very important military strategic significances. The successful development and trial application of communication tower health remote monitoring and active detection system based on Beidou system have accumulated experience for other high-tech fields based on high-precision real-time positioning.
ACKNOWLEDGMENTS
Our thanks to supported by science and technology project of State Grid Corporation of China (No. SGSHJX00KXJS1901531).

REFERENCES
[1] Wang S.L., Du Y., Sun J.X., Fang Q., Weng Y.C., Ma L., Zhang X.F., Wu J., Qin Q., Shi Q.S. Research Status of Deformation and Inclination Detection of Transmission Towers J. Telecom Power Technology. 2018, (35):91-92.
[2] Meng T. Research on the Adjustment Work of Transmission Line Poles J. Electric Engineering. 2018, (03):122-123.
[3] Hao Y.C., Su X.L., Zhao Q. E., Yan Q.X. The Design and Implementation of an Inclination Monitoring and Analysis Software for Transmission Line Tower based on Matlab J. Journal of Electric Power. 2014, (29):160-164.
[4] Gao P., Ji F.L., Wang J.H., Na L.D. Design of High precision Acquisition System for Power Grid Data Based on Beidou J. Microcomputer Applications. 2019, (35):58-61.
[5] GUO Jiang-tao, SHEN Jia, LIU Kun, et al. Research on electric power tower attitude monitoring technique using Beidou satellite technology J. China Science and Technology Information, 2017, 29 (17) :95-96.
[6] LIU Yan-li, TONG Jie, SUN Jian-ping, et al. Application of Beidou satellite short message technology in transmission line online monitoring system J. Electric Power Information and Communication Technology, 2016, 14 (11) :28-32.
[7] ZHU Bing, YE Shui-yong, SHAO Ming-sheng, et al. Study on power tower online monitoring system based on Beidou system J. Shaanxi Electric Power, 2016, 44 (4) :51-53,59.
[8] Cong L., Du Q.S., Dou Z., et.al. Research on Deformation Monitoring Technology of Power Tower Based on Beidou RTK Technology J. Power Information and Communication Technology. 2015, (12):24-29.
[9] Yao P.C.. Research and Application of BeiDou/GPS Single Frequency Reverse Network RTK Positioning Algorithm D. Xi’an: Chang’an University.2017.
[10] Luo W.G. Analysis the Ability of Network RTK Real-time Location Service Based on BDS J. Beijing Surveying and Mapping. 2019,(33):787-791.
[11] Liu M., Chai H.Z., Dong B.Q. Algorithm of Instantaneous Integer Ambiguity Resolution for Reference Stations of BDS Network RTK J. Journal of Information Engineering University. 2016,(17):760-763.
[12] Zhu H.Z., Li J., Wang C.Y., Xu A.G., Gao M. A method of BeiDou Navigation satellite system double difference network real time kinematic J. Science of Surveying and Mapping. 2017,(42):1-6+13.
[13] Gao W., Gao C.F., Pan S.G., Wang D.H., Wang S.L. Single-epoch Positioning Method in Network RTK With BDS Triple-frequency Widelane Combinations J. Acta Geodaetica et Cartographica Sinica. 2015, (44):641-648.
[14] Li C.G., Luo X.J., Wang C.W., Shi X.C., Liu W.J. Preliminary Performance Exploration of Flexible combination BDS/GPS Network RTK Positioning J. Journal of Navigation and Positioning. 2014,(2):66-71.