Research on online sag monitoring of transmission lines based on barometric pressure

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Abstract. Transmission line is an important part of power system, and sag is an important parameter to evaluate the running state of transmission line. Because of the complex system and the high power consumption of online monitoring application used nowadays, this paper proposes an online sag monitoring system based on high precision barometer and relative height measurement method. Firstly, precision barometer will be installed in the middle of line to calculate the relative height of measuring points. Secondly, the span of space distribution can be calculated which leads to complete the sag calculation. All the research above has passed the test.

1. Introduction

Transmission line is an important part of the power system and a basis part of the safe operation system. The sag measurement of high voltage transmission line is a very technical work during the operating maintenance, which is of great importance for the construction and safe operation. Sag must be focused during the design and operation of transmission line, and it must be controlled within the scope of the design provisions [1,2]. Due to line aging, operating load and the influence of the surrounding environment, the length of the wire will change slightly. This elongation or shortening is a small percentage compared to the actual length of the transmission line, but the variation in the sag is large[3]. If the sag is too small, the tensile stress of the line will be large, the load of the tower will increase, and the safety factor will decrease. In serious cases, accidents such as line breaking, tower falling and string dropping may occur. If the sag is too large, the safety distance of lines to the ground and the crossing objects is insufficient, the risk of power outage accidents caused by wind swing, dancing and jumping will increase [4]. Therefore, it is necessary to detect the transmission line sag and control the sag within the range required by the regulations to ensure the safety of the line and the equipment.

At present, there are field measurement and online measurement methods for sag monitoring. Due to the wide distribution of transmission lines and the complex environment, field measurement is difficult, the online measurement has been widely researched. Online monitoring methods include GPS/BDS monitoring, insulator angle monitoring and image recognition [5-7]. Among them, GPS/BDS has the problem of high-power consumption and complex algorithm. The change of insulator inclination angle with sag is not obvious and the error is large. The method of image measurement has
high power consumption, complex algorithm and maintenance\cite{8,9}. To solve these problems, this paper proposes a sag measurement method based on high precision barometer and relative height by installing high precision barometer in the middle of the line. The relative height of the measured point will be calculated, and the space distribution of the wire in the gap will be fitted to complete the sag calculation.

2. Architecture of sag monitoring
Transmission line sag monitoring is based on the spatial distribution of transmission lines. The height positions of specific points in the traverse are obtained through the measurement of air pressure/altitude to complete the calculation of traverse distribution. Its monitoring architecture is shown as Figure 1.

![Figure 1. Architecture of sag monitoring](image)

In the sag measurement based on the high precision barometer, it is only necessary to install the high precision barometer T1 at the point P in the wire and the high precision barometer T2 at the point H on the tower. When the system is installed, the distance and relative height between A and B on both ends of the wire can be accurately measured, and the relative height between point P and the both ends of the line can also be measured. The relative heights of T1 and T2 barometers can be calculated by the measurement of high precision barometers. Therefore, the coordinates of three points A, B and P can be obtained in space to complete the calculation of wire spatial distribution, and the line sag can be calculated finally.

3. Calculation method of sag

3.1. Relative height measurement
The hypsometric formula can be used to calculate the relative height based on atmospheric pressure. This formula can be used to calculate the difference of geopotential height between any two isobaric surfaces when the vertical distribution of temperature and humidity is known. For the pressure measuring points T1 and T2 in the sag monitoring system, the pressure distribution at T1 and T2 can be considered as isobaric surface. The formula for calculating the altitude H of the measured point is as follows.

\[
h = \frac{\left(\frac{P_0}{P}\right)^{\frac{1}{1.379}} - 1}{0.0065} \times (T + 273.15)
\]
In the formula, $P_0$ is the standard atmospheric pressure with the value of 101.325 kPa. $P$ is the atmospheric pressure actually measured at the measured point, and the unit kPa. $T$ is the actual measured temperature, and the unit is °C.

The relative height difference can be calculated from the altitude values measured at T1 and T2. The method of measuring the relative height with two points is more accurate than the method of directly calculating the altitude with the pressure height formula, which can more effectively reduce the height measurement deviation caused by local meteorological deviation and temperature drift.

3.2. Calculation algorithm of space distribution

Generally, there is a long distance between the two poles and towers in the transmission line. Because the distance between the two suspension points is very large, the shape of the lines hanging in the air is only related to the weight and distance, and the material and rigidity of the line have no effect on it. In this way, we can define the line as a flexible chain. Therefore, the line can be considered to bear only the force along the tangent direction of itself, that is, the axial tension, but not the bending moment. Then we assume that the line on the role of the load in the same direction, and the load is with average distribution to support the suspension. So the shape of line is catenary, the line sag simulation should be used catenary equation. The formula of catenary is as follows in the coordinate system [10,11].

$$y = a \cosh \left( \frac{x + b}{a} \right) + c$$

In the formula, $y$ is the ordinate of a point of the line, and $x$ is the abscissa of a point of the line. $a$, $b$ and $c$ are constants that determine the shape of the catenary.

The selection of the origin position of the coordinate system where the catenary is located, the density and temperature of the wire will all lead to the different values of $a$, $b$ and $c$, but it will not affect the shape of the catenary, that is, it will not affect the sag measurement. Therefore, when the running state of the line is change, the positions of A and B at both ends of the line will be fixed, and the height of point P measured by the high-precision barometer will change. At this time, the spatial distribution of the conductor will change.

4. Design of high precision barometer

4.1. Design of air pressure measurement module

In order to improve the measurement accuracy, the MEMS barometer is used to design. Since altitude calculation requires temperature correction, a high-precision temperature and humidity chip will be built into the barometer. The basic architecture is shown below.
In this design, the LPS22HB of STM is used in the air pressure module, which has fast response time and low power consumption. The module has 24-bit sampling accuracy, and the pressure measurement accuracy is ±10Pa. Temperature and humidity chip is used SHT35, its temperature measurement accuracy is ±0.1℃.

The function of MCU is to calculate and analyse the collected data, and control the wireless module to realize the remote transmission of data. In this paper, nRF52832 chip is used as MCU chip. This chip has strong computing power and floating-point computing technology, which can meet the needs of data processing.

The power supply module of the air pressure module will be determined according to the place where it is used. The monitoring module installed at point P will be powered by coil energy, while the monitoring module installed at point H will be powered by solar energy.

4.2. Design of data communication

The sag calculation needs the data of the two monitoring points and the pre-measured position data of A and B. Therefore, the data monitored by the barometer will be transmitted to the cloud, and the data communication architecture is shown in the figure below.

The communication between the air pressure module and the communication node is LORA. LORA has the characteristics of long transmission distance and low power consumption, which is suitable for scenes with small amount of data. The long-distance communication can adopt NB-IoT or the private network of power company to ensure the stable transmission of data to the cloud. In the case with poor communication signal, a cascade transmission network of AD hoc network can be built based on LORA to realize wireless data uploading.

5. Test

In the lab, the space between two office buildings was used to verify the function of barometric sag measurement using ropes. The rope needs to be heavy enough to hang in a regular arc at both ends. With the ground as the origin horizontal plane, the coordinate of point A is (0,10.3), and the coordinate of point B is (40,14.5). The horizontal position of point P is 4.5m away from point A, and point H is coincident with point B. In the experiment, the measured pressure of point P is 96.314kPa, the pressure of point H is 96.261kPa, and the temperature is 23.5℃. The height difference between point P and point H can be calculated as 4.8251m, so the coordinate of point P can be obtained as (4.5,9.6749). After calculation, the spatial distribution of the rope can be obtained, which is as shown in the figure below. The lowest point height is 9.249m, and the sag is 1.05m and 5.25m, which is consistent with the field measured value.
6. Conclusion
In this paper, a sag measurement method based on high precision barometer and relative height is proposed. Based on the hypsometric formula and the catenary module of transmission line, the calculation and display of the spatial distribution of the line within the transmission line gap can be realized by installing a high precision barometer in the middle of the line and combining with the installation site data. The monitoring system has low power consumption and realizes the remote transmission of data communication, which has certain practicability. Finally, the system developed in this paper has passed the laboratory function verification, and can realize the measurement of sag.

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