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METHODOLOGY OF ICE COATING MONITORING ON OVERHEAD TRANSMISSION LINES CONSIDERING MISALIGNMENT USING WIRELESS COMMUNICATION CHANNEL SENSORS

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ABSTRACT

At present, the problem of timely examination of overhead transmission lines is acute. To solve it, devices with the ability to organize wireless data transmission without binding to transmitting stations were developed, including a set of sensors for measuring the parameters of diagnosed high voltage transmission lines. The use of modern electronic technologies and power schemes ensures the autonomy of the device, since it does not depend on external power sources, but makes power take-off directly from the line. Wireless data transmission is carried out with the help of the wireless network for process automation (WNPA) modules. Such a communication channel allows organizing not only inexpensive, but also capable of self-recovery network. The method of monitoring ice coating on overhead lines based on the mathematical model of chain line is considered. It allows identifying the current sag and elongation of the wire in a span, the force of its tension, taking into account the misalignment of wires on the line, based on the data obtained from wireless sensors.

Keywords: wireless sensor, inspection, diagnostics, monitoring, overhead power line, wireless data transmission, wireless network of process automation modules.

INTRODUCTION

One of the most serious causes of accidents in high voltage electric power systems is the formation of a dense ice precipitate - owing to freezing of super cooled droplets of rain, drizzle or fog at temperatures from 0°C and lower on the wires of high voltage transmission lines.

In accordance with the map of ice loads, the Republic of Tatarstan refers mainly to the second risk group (the normative thickness of ice coating on the wire is over 15 mm). The number of temperature transitions through 0°C has increased, which has led to an increase in the probability of ice coating. In conditions of a relatively mild winter, with a sharp drop in the ambient air temperature from positive to negative, drops of water settle on wires and an avalanche-like process of formation of a thick ice coating reaches a thickness of several tens of millimeters and increases manyfold the weight of wires.

Deposits of ice, frost and wet snow pose a great danger for the normal operation of overhead transmission lines (OHTL). They can cause: a) misalignment of wires and their rapprochement; b) convergence of wires during the jump due to non-simultaneous discharge of ice; c) intense swinging, causing short circuits between wires, burns of wires, and in some cases damage of the linear reinforcement and fixtures; d) significant overloading of wires and their breakages; e) destruction of supports as a result of breakage of wires during overload because of ice, when the unbalanced tensions on the supports of remaining wires are significantly higher than designed, also when ice is combined with a strong wind; f) overlap of linear insulation of overhead lines during defrosting due to a significant decrease in the ice discharge characteristics of insulators in comparison with their moisture discharge characteristics, according to which the level of linear insulation is usually chosen [1].

It should be taken into account that it is necessary to accurately localize the area or defect having problems with ice, since it is often difficult to move along an OHTL (blurred roads after rain, deep snowdrifts, natural obstacles, e.g., marshland, terrain, etc.).

Currently, stationary devices installed on transmission lines have been designed to monitor the state of overhead lines [2, 3]. On their basis, a system for monitoring ice formation was created. The hardware of these devices [2] has a distributed architecture, which includes a set of sensors for measuring line and environmental condition parameters, and means to receive and transmit data.

To monitor ice formation on OHTL, the following parameters are measured:

- wire and ambient temperatures;
- relative humidity;
- sag angle of the wire.

Any high-voltage OHTL includes supports, structures for holding wires at a given distance from the ground and from each other. Depending on the method of hanging wires, supports are divided into two main groups:

- intermediate supports, on which the wires are fixed in supporting clamps;

- anchor-type supports, which serve for pulling wires (on these supports the wires are fixed in tension clamps).

It should be borne in mind that on worn-out overhead power lines, the effect of dragging from one span to another (misalignment) is observed, which, over time, leads to appearance and development of defects in linear armature (traverses, couplings, line accessories, etc.).

METHODS

In this regard, a mathematical model is proposed that takes into account the misalignment of wires on OHTL.

First, we derive the balance equation for the wire. In the section of theoretical mechanics studying suspension structures, these systems are united by the common name of threads or chain lines. Let us consider the effect of an elastic deformation on a thread, according to Hooke's law. The problem will be solved by rigorous methods (within the model of an absolutely flexible thread) [4]. We arrange the thread as shown in Figure 1.

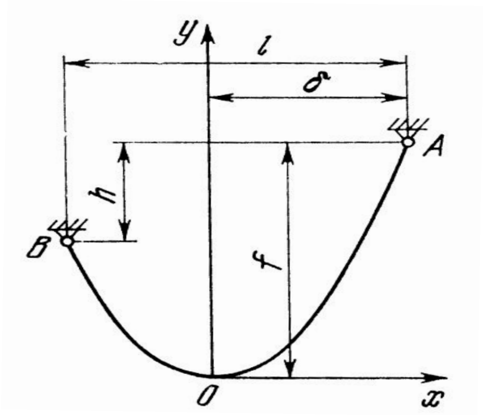

Figure-1. Model of a flexible thread with basic geometric parameters.

For a stretched thread, the gravity force q per unit length of the thread is a variable value depending on the tangential tension T. Therefore, for a thread subject to linear deformation, the value of q in the equation must be expressed via the law of tension of the thread.

$$q = \mu g = \frac{\mu_0 g}{f(T)} = \frac{q_0}{f(T)}, \quad (1)$$

where q_0 is the force of gravity per unit length of the unstretched thread, $f(T)$ is the law of elongation.
After simplifications, we obtain:

$$f = h + a\left[chu_1 - 1 + \frac{\alpha^*}{2} a q_0 (ch^2 u_1 - 1)\right], \quad (2)$$

We now have just to find the length L of the stretched chain line. Integrating in the range from α_1 to α_2, we obtain:

$$L = a(tg\alpha_2 - tg\alpha_1) + \frac{\alpha^*}{2} q_0 \left[\frac{tg\alpha_2}{\cos\alpha_2} - \frac{tg\alpha_1}{\cos\alpha_1} + \ln tg\left(\frac{\pi}{4} + \frac{\alpha_2}{2}\right)\right] \quad (3)$$

$$L = L_0 + \frac{\alpha^*}{2} a^2 q_0 \left[chu_2 shu_2 - chu_1 shu_1 + \left(\frac{l}{a} - \alpha^* q_0 L_0\right)\right]. \quad (4)$$

Calculations are greatly simplified if the boundary points A and B are on the same level. Indeed, in this case $h = 0$ and from the second equation (4) there follows a unique solution

$$u_1 = -u_2(\alpha_1 = -\alpha_2), \quad (5)$$

which is obvious by virtue of symmetry.

The remaining two equations take the form:

$$u_2 = \frac{1}{2}\left(\frac{l}{a} - \alpha^* q_0 L_0\right), \quad shu_2 = \frac{L_0}{2a}. \quad (6)$$

For $h = 0$, the expressions for the length of the extended chain line and the sagging of the wire are also simplified. Indeed, taking into account equalities (2), we obtain:

$$L = L_0 + \frac{\alpha^*}{2} a q_0 \left[l + L_0 (chu_2 - \alpha^* a q_0)\right], \quad (7)$$

$$f = a\left(chu_2 - 1 + \frac{\alpha^*}{8} q_0 \frac{L_0^2}{a}\right). \quad (8)$$

Under the assumptions made, all the formulas obtained are exact.

If we exclude a, and express L_0, we obtain:

$$L_0 = \frac{-u_2 \pm \sqrt{2\alpha^* l q_0 shu_2 + u_2^2}}{\alpha^* q_0} \quad (9)$$

The module of real value of the variable u lies within the range $10^{-3} < u < 1$. The denominator of the last expression has the order of 10^{-6}. The number u_2 is positive, therefore, the negative root will be an indirect one.

RESULTS

The following methodology is proposed for monitoring ice on OHTL described for the case of a single sensor. On an OHTL, a sensor is installed near the wire fastening point. The input information from the sensor is collected: the angle of inclination of the tangent to the wire relative to the horizon, the temperature of the wire. It is assumed that the monitored OHTL at the launching of the monitoring system are in a steady state, free from ice coating. There are three possible states of the system:

a) The system for monitoring ice formation is in the calibration mode (Figure-2). In the absence of ice coating (humidity less than 80%, wire temperature above 0°C), the length of the unstretched wire is calculated cyclically: according to formula (9), L_{0t} is calculated and the corresponding wire temperature value t_0 is stored in memory. Data are statistically averaged.

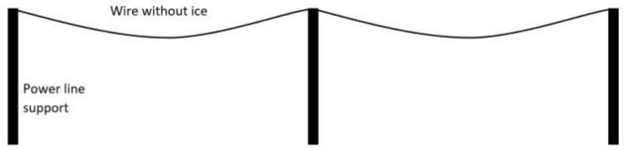

Figure-2. Line without ice deposits on wires.

b) The system for monitoring ice formation enters the tracking mode from the calibration mode at the moment of ice coating formation. The length L_0 is calculated by the formula $L_{0t}(1+\delta(t-t_0))$. From formulas (8), we find $a=\frac{L_0}{2shu_2}$, calculate the linear mass of the wire with ice $q=\frac{\left(\frac{l}{a}-2u_2\right)}{\alpha^* L_0}$. By formula (3) we find a sag, and the tension force according to formula $T=aqchu_2$. (Figure-3).

Figure-3. Line with ice deposits on wires.

c) When the parameters of the environment change and the ice formation conditions disappear (humidity less than 80%, wire temperature above 0°C) and q returns to the value of q_0, the system for monitoring ice formation again switches to the mode described in paragraph 1.

On worn-out OHTL of low and medium voltage during ice formation there is a misalignment of the linear reinforcement (tug of wire between the spans) due to uneven discharge of ice coating, for example, during swinging of wires. Observation showed that in most cases the process of clearing a span from ice coating is avalanche-like, releasing that span completely.

DISCUSSION OF RESULTS

We propose the following method to account for these facts in the tracking mode. We track the discontinuous changes in the angle of inclination of the tangent to the wire, through the first and second derivatives. During tracking, two optional developments are possible:

a) Changing the angle to a smaller value indicates the release of ice coating. In this case, we assume that the linear mass of the wire q is returned to the value q_0. Then, using formula (9), we can calculate the new length of the unstretched wire L_0 (re-calibrate) and return to the normal tracking mode.

b) The change in the angle to a higher value indicates the pulling of the wire from the adjacent span (Figure-4). In this case we assume that the linear mass of the wire with ice after the jump has not changed. Using formula (9), taking q_0 as q, we calculate the new length of the unstretched wire L_0. Fixing the current wire temperature as t_0, we return to the normal tracking mode.

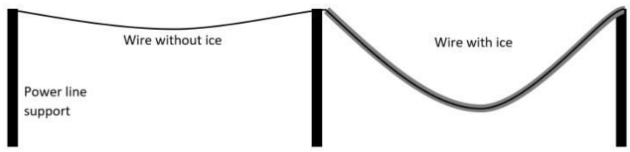

Figure-4. Line with misalignment of wires in adjacent spans.

These assumptions are verified on SMG-16 system, put into trial operation in PAO *Tatneft*.

CONCLUSIONS

A technique for monitoring ice on OHTL wires has been developed based on the mathematical model of chain line [4], which makes it possible to determine the current sag and elongation of the wire in the span, the force of its tension, taking into account the misalignment of wires on the line. Implementation of this technique will allow detecting the appearance of ice coating on OHTL, which ensures timely implementation of measures to prevent emergencies on the line (optimization of ice melting on wires).

Experimental samples of WNPA module working with Bluetooth, Wi-Fi, PLC, Ethernet, USB, RS-485, IrDA communication protocols will be designed to monitor the status of objects, the automation of corporate and public buildings through the collection and transmission of information from external sensors, automatic relaying of transmission data, creating continuous information coverage of large area with a broadcast access to all nodes on the network [5-15].

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