Imitation and Physical Modeling of the Influence of Ice Coating on the Propagation of Location Signals on the Wires of Overhead Transmission Lines

V.A. Kasimov, R.G. Minullin, Yu.V. Piskovatskiy, E.M. Basharova

Abstract: *This paper is a continuation of the work originally published in 2018 International Youth Scientific and Technical Conference Relay Protection and Automation (RPA). The article presents the results of the model and experimental studies on the detection of ice coating on the wires of overhead transmission lines by location method. The influence of ice coating on the propagation speed and attenuation of the probing signal were analyzed.*

Index Terms: *glaze-ice and rime deposits, high-frequency section, laboratory research,location method, overhead transmission lines.*

I. INTRODUCTION

Overhead transmission lines (OHTL) have a long length and are the least reliable elements of the power system. The most severe problem for electric networks is ice accidents, which are caused by the formation of an ice coating on the wires of OHTL, which in combination with wind loads can cause damage to the structure of the OHTL (wire breakage, breakage of crossarms and shoes, etc.) [1], [2].

Now, the Russian Federation has introduced information systems for detecting ice coating on wires of OHTL, implementing a gravitational method, which consists in weighing the wires of OHTL using load cells [3], [4]. Methods are also being developed based on changing the propagation conditions of high-frequency (HF) signals along a line section at the formation of ice coating on wires [5]-[7]. One of them is the location method.

The action principle of the location method for detecting ice coating on the wires of OHTL is to send pulse signals to the line, followed by their reception after a reflection from the obstacles of the surge resistance of OHTL. The obstacles can be spur lines, HF chokes, conductor transpositions.

Detection of ice coating is achieved by the appearance of additional attenuation of the location signals and their delay in propagation, due to the fact that the ice coating is imperfect dielectric, in which energy absorption occurs and the propagation speed of electromagnetic waves decreases [8].

The location device is connected to the operating OHTL with connection equipment (coupling capacitor (CC) and coupling filter (CF)), due to which the HF equipment is decoupled from thepower-frequency voltage [8, 9]. High-frequency chokes (HFC) are installed on the line to prevent the shunting of HF equipment by substation busbars. Theconnection scheme of the locating device to the operating OHTL is shown in Fig.1.

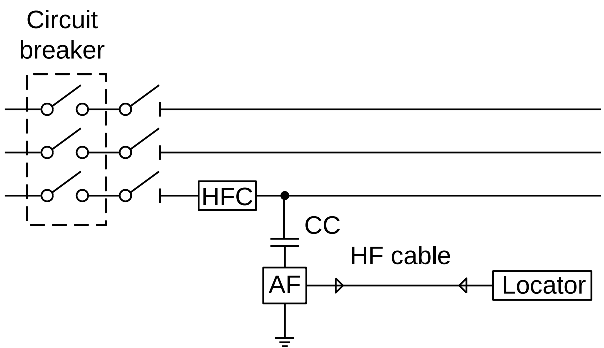

Fig. 1. The connection scheme of the locating device to the OHTL with elements of the high-frequency section, where HFC – high-frequency chokes, CC – coupling capacitor, CF – coupling filter, HF cable – high-frequency cable; locator – locating the device

II. LOCATION COMPLEX FOR LABORATORY RESEARCH

To carry out laboratory and field measurements on existing OHTL, a hardware-software complex was created, which includes a device for detecting ice coating on the wires of OHTL (locator) and software for processing the results of measurements and their visual presentation. In the locator, 1) Bordo B-332 [10] was used as an impulse generator, 2) the digital oscilloscope Bordo B-423 [11] was used as a pulse receiver. The device was connected to the HF section through a branching filter (5), which reduces the influence of the device on the HF communication equipment. The HF section included: CC (6), CF (7), HFC (8), OHTL wires (9). From the impulse generator (1), the sounding impulses entered the line. The reflected impulses went from the line to the receiver, which processed and transmitted the data to a computer (3).

Revised Manuscript Received June 14, 2019
V.A. Kasimov, KazanStatePowerEngineeringUniversity, Kazan, RussianFederation.
R.G. Minullin, KazanStatePowerEngineeringUniversity, Kazan, RussianFederation.
Yu.V. Piskovatskiy,KazanStatePowerEngineeringUniversity, Kazan, RussianFederation.
E.M. Basharova, KazanStatePowerEngineeringUniversity, Kazan, RussianFederation.

TheworkwasperformedwithfinancialsupportfromtheMinistryofEducation andScienceoftheRussianFederationunderAgreementNo. 14.574.21.0141 datedSeptember 26, 2017, theuniqueprojectidentifier RFMEFI57417X041.

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With the help of a specially developed program, the impulse generator and the digital oscilloscope were controlled, the reflected signal was isolated against interference, the formation of ice coating was detected and data was transmitted to a server (10) through the communication system (4). Transmission of information to the control center was carried out using an industrial GSM modem. The formation of the image on the display screen, setting, management and data logging were carried out using the software "Glaze 0.9" [12].

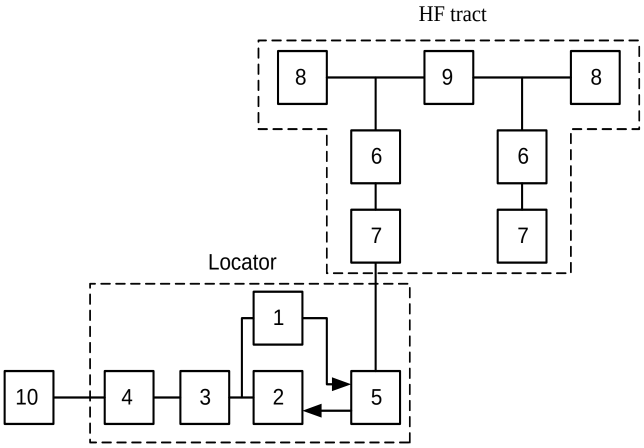

Fig. 2. Functional diagram of the location-sounding device

A. The calculation of the additional delay of the reflected signal

Detection of ice coating on the wires of OHTL by the location method is reduced to the problem of determining the param of the received signal reflected from the end of the line section. With the formation of ice coating on the wires of OHTL, the propagation velocity of the HF signal decreases (increases the propagation time of the probing and received reflected signals). The attenuation increases, while the shape of the reflected signal is preserved. This fact allows us to calculate the change in the propagation of HF signals by the correlation method [13].

Suppose there is the current reflectogram $RFG_{cur}(t)$, which includes the reflected impulse $IMP(t)$ of finite length τ_{ref} and a sounding impulse. To search for this impulse in the moving reflectogram for the $RFG_{cur}(t)$ time window with the length τ_{ref}, calculate the inner products of $RFG_{cur}(t)$ and $IMP(t)$. Thus, we compare the segment of the reflectogram, including that reflected from the end of the OHTL impulse of finite length, with the sounding impulse, and the magnitude of the inner product estimates the degree of similarity of the signals.

In the functional space of signals, this degree of connection can be expressed in reduced units of the correlation factor, i.e. in the cosine of the angle between the signal vectors, and, accordingly, will take values from 1 (full coincidence of signals) to -1 (direct opposite) and does not depend on the value (scale) of the units of measurements.

Thus, to calculate the additional delay, it is necessary to calculate the cross-correlation function (CCF) of the current reflectogram RFG_{cur} and the sounding impulse IMP and select the maximum values. The distance along the time-base between the two will be equal to the time of propagation of the impulse signal from the beginning of the line to its end and back again. The CCF is calculated by the Eq. 1.

$$R(i) = \frac{cov(RFG_{cur[i,i+k-1]}, IMP)}{\sigma_{RFG_{cur[i,i+k-1]}} \sigma_{IMP}} \quad (1)$$

where $R(i)$ – the value of the CCF at the i-th point of the reflectogram;

$cov(RFG_{cur[i,i+k-1]}, IMP)$ – covariance of the reflectogram segment and sounding impulse;

$\sigma_{RFG_{cur[i,i+k-1]}}, \sigma_{IMP}$ – root-mean-square deviations of the reflectogram land and sounding impulse, accordingly.

B. Calculation of the echo amplifier

To determine the echo amplifier we calculate the effective range of the reflected signal by the Eq. 2.

$$U = \sqrt{\frac{1}{T}\int_0^T U(t)^2 dt} \quad (2)$$

Substituting in the expression 2 numerical values from the table of construction of the current reflectogram, we get Eq.3:

$$U\delta_{IMP} = \sqrt{\frac{1}{k}\sum_{m=1}^{k}(IMP(m) - \overline{IMP})^2} \quad (3)$$

Where $\overline{IMP}$ – the half-value of the reference reflected signal;

$IMP(m)$ – the value at point m on the reflectogram.

III. MATHEMATICAL MODEL

A simulation model in the PSCAD environment was developed to study the features of the propagation of location signals along HF sections of OHTL. The model of the HF section of the electric transmission lines includes:

- Multiwire lines near the surface of the earth (phase conductors and ground wires of the OHTL), in the presence of a branch line – branch from them. In this case, the OHTL is divided into sections, each of which allows to separately set the brand and location of the wires in space with respect to the ground;
- connecting devices consisting of CF with CC, HF cables;
- processing devices consisting of HFC – separation circuits, which are a special kind of branching filter;
- on overhead lines with transposition – transposition of the phases of the OHTL;
- HF bypasses on transmission substations;
- high-voltage equipment of the substation, located behind the HFC is represented by equivalent active resistance and capacitance.

So how exactly does the transmission line determine the conditions for the signal transmission along the HF section? In the general scheme of the HF section, it is convenient to distinguish the line section, which begins and ends at the interface points of connecting devices, to the wires of the transmission lines, as shown in Fig. 3.

Also in the developed simulation model, there is a square-wave generator – a standard component of the PSCAD library – a single-phase source that provides the generation of impulses of a given duration and amplitude. When location sounding existing transmission lines, impulses with a duration of 1-5 microseconds are typically used. The generator is connected to the HF cable. In addition, an oscilloscope is connected to this point, which records the sounding and reflected signals with a given time step. The result is a reflectogram.

The CF performs the following functions: equalize the reactive resistance of the CC at operating frequencies, grounds the lower coating of the coupling capacitor at a frequency of 50 Hz, serves as a matching element between the HF cable and the line section.

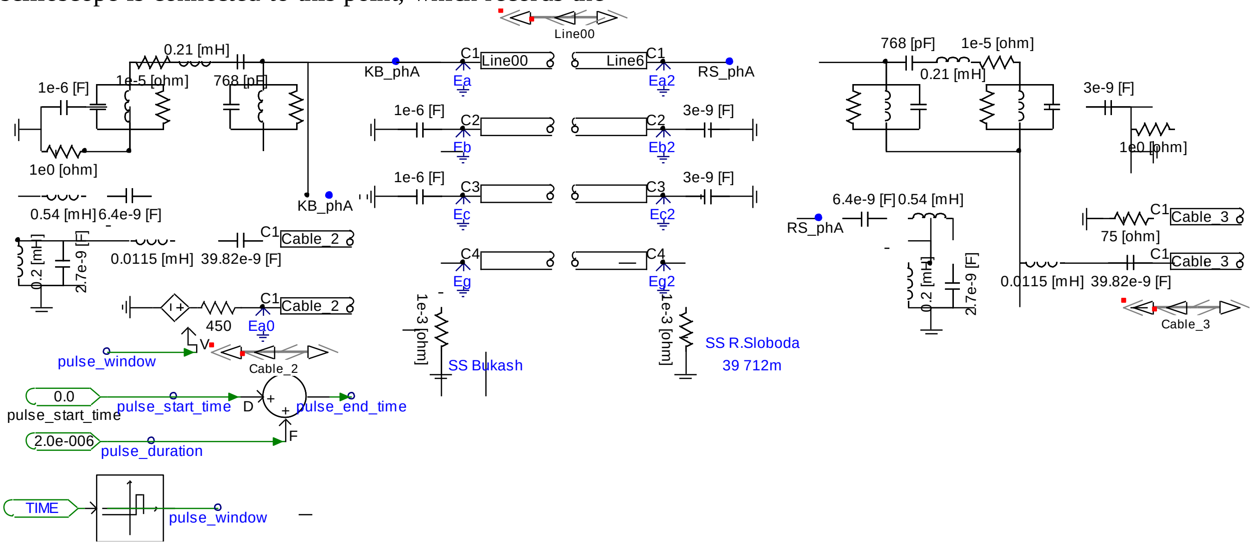

Fig. 3. Schematic representation of the HF sectionelements of OHTL in the PSCAD environment

The processing device consists of an HFC with a tuning element. The choke slices into the working wire of the line between the interface point of the CC and the substation busbars.

Line HF sections form phase wires of OHTL and ground wires. If the OHTL is a double circuit, then the phase wires of the second circuit are taken into account. Transmission line wires are represented as a coaxial cable with zero thickness of the insulation barrier and confinement. Although, the PSCAD software environment has standard libraries for Tline OHTL. This choice of the model makes it possible to simulate ice coating on the OHTL wire by adding a dielectric and also to set the area of the core of the aluminum conductor.

At the same time, param for this component of the construction of OHTL must be set: the height of the suspension above the ground; the distance between the phase wires and earth-wire; the length of the OHTL; the radius of the iron core; the radius of aluminum lay; the volume resistivity of the core; the volume resistivity of the earth. The use of a coaxial cable makes it possible to estimate the delay of the location signals that occur when glaze-ice and rime deposits (GIRD) are formed on the wire. For this purpose, the dielectric characteristics of the ice coating are set as the dielectric characteristics of the cable insulation.

Fig. 4 shows a comparison of the reflectogram modeled in the PSCAD software environment and the reflectogram obtained by sounding an OHTL with a voltage of 110 kV. Of particular interest is the field on the reflectogram corresponding to the reflection from the end of the OHTL (in the figure highlighted by an oval). The correlation factor for a given field is usually in the range of 0.9 to 1.

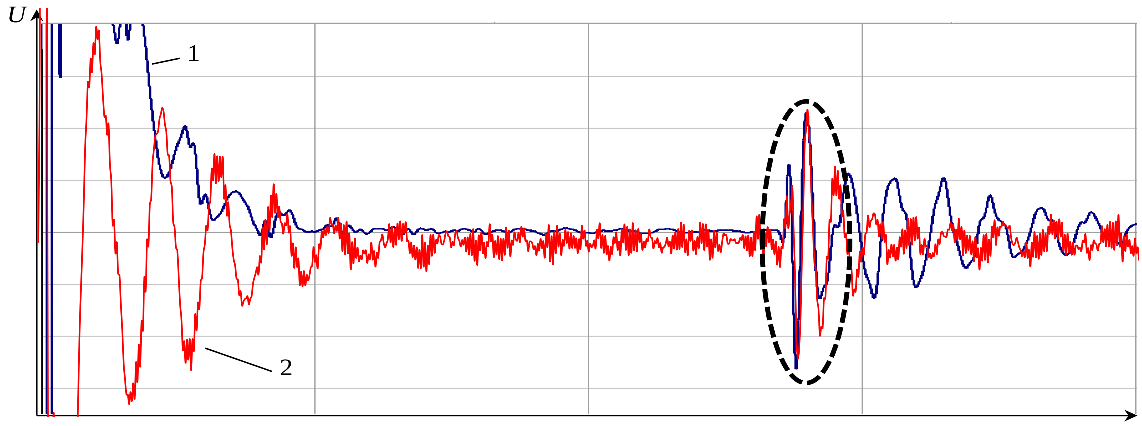

Fig. 4. Modeled in PSCAD environment (1) and real (2) reflectograms of 110 kV OHTL

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IV. PHYSICAL MODEL OF OHTL

The physical model of OHTL is located in the territory of the experimental area "10/0.4 kV distribution circuits" of the Kazan State Power Engineering University. It allows to experimentally determine the influence of GIRD on the propagation conditions of the HF signal. The investigated line is a three-wire line, made with a wire of the AC-50 mark, has a length of 40.6 m and the distance between the wires is 0.6 m [14].

When planning the experiment, the materials [15] were used. Fig. 5 shows a single-line normal electric diagram of the experimental area, marked sites of fixation of ice coating.

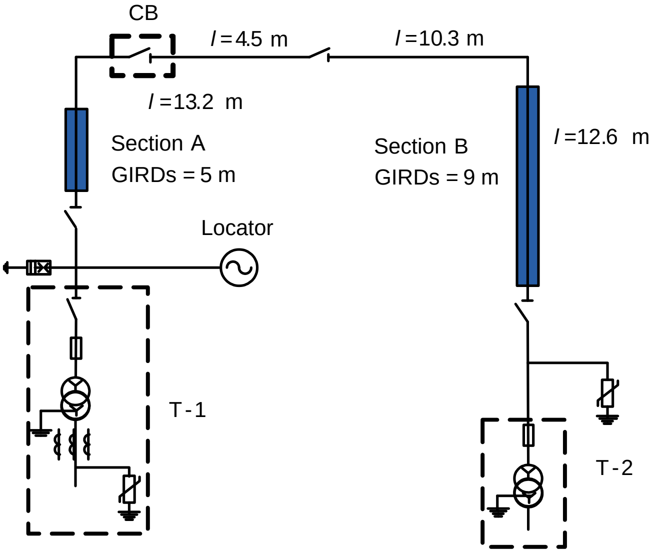

Fig. 5. Normal electric diagram of the experimental area"10/0.4 kV distribution circuits"

To simulate the formation of ice coating on the wires of the OHTL, ice cylinders with a density of about 0.9 g/cm^3, length 1 m and diameter 110 mm were used.

The 42 pieces of ice cylinders on three phase wires of the OHTL were attached, which together amounted to 14 m of the GIRD on three phase wires of the OHTL, with a wall thickness of the ice muff of 50-55 mm. The GIRD were attached on two sections – A and B. In section A, the length of the GIRD was 5 m, in section B – 9 m (Fig. 5).

In order to verify the model suitability implemented in the PSCAD environment to simulate the propagation of a sounding signal along a line HF section, measurements of attenuation and an additional delay of the sounding signal in the presence of ice coating on the wires of the OHTL physical model were carried out. From the side of KTP 10/0.4, the locator was connected according to the “wire-to-ground” scheme. As a probing signal, a video pulse with a duration of 50 nsec and an amplitude of 4 V was chosen. The conditions of the experiment were as follows: ambient temperature -6°C, relative air humidity 85% without meteorological precipitation.

Direct independent multiple determinations of the propagation time of the HF signal during reflection from the end of the OHTL, as well as the amplitude of the reflected impulse with different lengths of the ice muff, were carried out. The results are presented in graphs. The graph (Fig. 6) shows the dependence of the additional delay on the length of the ice muff (the measured value is the solid line; the calculated value is the dashed line). As can be seen from the graph, the measured value of the additional delay practically does not differ from the calculated value and has a linear dependence on the length of the ice muff.

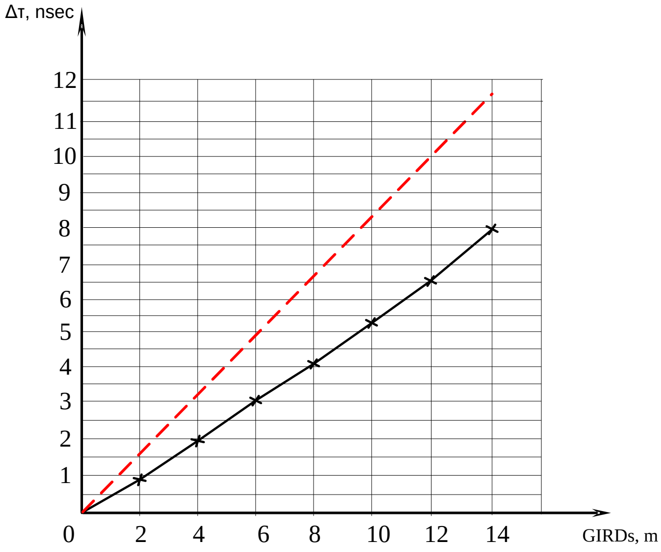

Fig. 6. Dependence of the additional delay on the length of the ice muff on a 10 kV OHTL (the measured value is the solid line; the calculated in PSCAD environment is the dashed line)

Fig. 7 shows the amplitude dependence of the reflected signal on the length of the ice muff (the measured value is a solid line; the calculated value is a dashed line). The graph shows that with the increasing length of ice coating, the amplitude of the reflected impulse decreases, while the calculated value of the decrease in the amplitude of the reflected impulse turned out to be less than the measured value. The discrepancy in the results is primarily due to the assumptions made in the mathematical model of the OHTL.

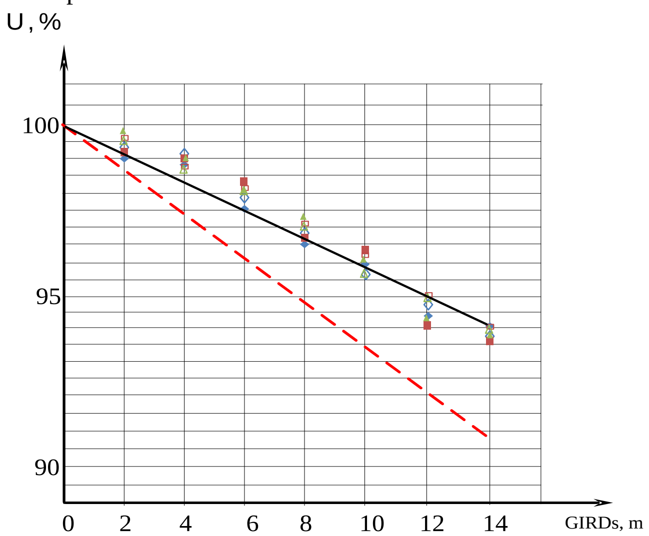

Fig. 7. The amplitude dependence of the reflected signal on the length of the ice muff on a 10 kV OHTL (the measured value is a solid line; the calculated in PSCAD environment is a dashed line)

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V. CONCLUSION

The conducted research on the physical and mathematical model of the OHTL confirms the possibility of using existing OHTL methods of ice coating v (in particular, location method), based on changes in the conditions of the propagation of HF signals along the line HF section. These methods have sufficient sensitivity.

ACKNOWLEDGEMENT

The authors would like to thank OJSC "SetevayaKompania" (Grid Company of the Republic of Tatarstan) for technical support.

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