Determination of ice deposits thickness on overhead power lines conductors by location method

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***Abstract*: This abstract describes the location method of ice deposits detection on overhead power lines. The researchers examine influence of ice deposits on parameters of reflected location signals. The method of ice deposits thickness determination on overhead power lines by analyzing the location signal attenuation and delay is offered in the article. The method of subdividing power lines into location probing segments to identify the ice deposits thickness is considered.**

Keywords: overhead power lines, ice deposits on the wires, pulsed signal location probing, attenuation and delay of the reflected signal, thickness of ice deposit, distribution of ice deposit formations according to the thickness along the line.

LEGEND AND ABBREVIATIONS

HF	*High Frequency*
GID	*Glass-Ice Deposition*
OPL	*Overhead Power Lines*

Glaze-ice and rime depositions on overhead power lines may result in damaging of wires and transmission towers. Monitoring of ice formation is necessary in order to prevent these damages. One of the methods to control ice depositions is pulsed signal location method [1, 2]. Pulsed signal location probing device is connected to high frequency channel of transmission line.

According to the pulsed signal location method for power lines diagnostics, information is sent by the pulses, which are reflected from existing obstacles of a line surge-impedance. End of lines, attach areas of taps to power lines, junctions of overhead lines with intermediate cables, as well as deliberately inserted obstacles in the form of HF stopper circuit cause significant changes of self-surge impedance. Studies of sensitivity and stability [3] of pulsed signal location method have shown that due to digital signal processing it is possible to discover even minor changes of the line impedance, a priori existing in the line.

Ice deposition on wires cause changes on location signal parameters: amplitude U and propagation velocity v get reduced, i.e. additional signal attenuation $\Delta\alpha$ and delay $\Delta\tau$ in a line link occur due to the dielectric properties of GID. If the surface of a power line is covered with ice deposits then the electromagnetic wave propagates in an imperfect dielectric, and a portion of the wave energy goes for the heating of ice coating. The biggest change in the signal is caused by pure ice coating, as it forms the densest deposit. Increase of attenuations and delays, caused by ice deposition, depends on ice thickness and length of icing area.

Thus, signal location method allows controlling the whole power line. At the same time, average ice thickness is determined along the line. In this case, it is impossible to differentiate between slight-thickness ice deposition of the whole overhead power line and dangerous concentration of ice on its separate areas. The method of subdividing power lines into location segments with spotted imperfections is used to prevent this drawback.

When considering modal components according to source [4], attenuation of line link with due regard to ice depositions is increased mainly because of attenuation change in the principal mode. Variations of attenuation coefficient $\Delta\alpha$ (dB/km) and phase coefficient $\Delta\beta$ (rad/km) for non-symmetrical line with identical wires, covered with ice, comparing to coefficients for the lines with identical wires ice-free are determined by the following formulas [4]:

$$\Delta\alpha \approx \frac{2\pi 10^{-7} f 10^{3}\,\mathrm{tg}\,\delta_{Ice} 10^{3} K \ln(1+b/r)}{0.115(Zp-60K\ln(1+b/r))\varepsilon'_{Ice}(1+\mathrm{tg}^2\,\delta_{Ice})};$$

$$\Delta\beta \approx \frac{2\pi 10^{-7} f 10^{3}\cdot 10^{3} K \ln(1+b/r)}{(Zp-60K\ln(1+b/r))}\left(1-\frac{1}{\varepsilon'_{Ice}(1+\mathrm{tg}^2\,\delta_{Ice})}\right);$$

where Z – wave impedance of the principal mode, defined reference to losses caused by ice depositions; p – number of wires in bundled phase; r – radius of bundled phase component; K – coefficient, that takes into account number of wires in bundled phase; ε'_{Ice} – real part of complex ice dielectric constant; and $\mathrm{tg}\delta_{Ice}$ – dielectric loss tangent.

According to the source [4], attenuation for line links in OPL phases is determined for the mode 1 (Z_1 = 360 Ohm), and for intraphase and internal ground wire links – intraphase and internal ground wire modes (respectively Z_{IPh} = 200 Ohm, Z_{IGW} = 240 Ohm).

Signal delay is determined according to max correlation of reflected signals. In order to calculate GID influence on signals it is necessary to use group velocity. Ice has abnormal dispersion in terms of frequency index of location device functioning. Group velocity of signal propagation is calculated as follows:

$$v_{gr} = \left(\frac{1}{v} - \frac{f\mathrm{d}v}{v^2\mathrm{d}f}\right)^{-1};$$

$$v \approx \left(\frac{10^{-7}\cdot 10^{3} K \ln(1+b/r)}{Zp-60K\ln(1+b/r)}\left(1-\frac{1}{\varepsilon'_{Ice}(1+\mathrm{tg}^2\,\delta_{Ice})}\right)+\frac{1}{v_0}\right)^{-1},$$

where v is phase velocity when GID is occurred on wires, in km/sec; v_0 – velocity without GID on wires, for principal mode $v_0 \approx$ c (velocity of light).

For example, Figure 1 shows projected reliance for steel aluminium wires (brand-names AS 120/19 and AS 150/19) with amplitude U and signal delay $\Delta\tau$ from ice deposition walls b (Figure 1, *a*, *b*), from the length of wires covered by ice deposition l (Figure 1, *c*, *d*) and from frequency f (Figure 1, *e*, *f*).

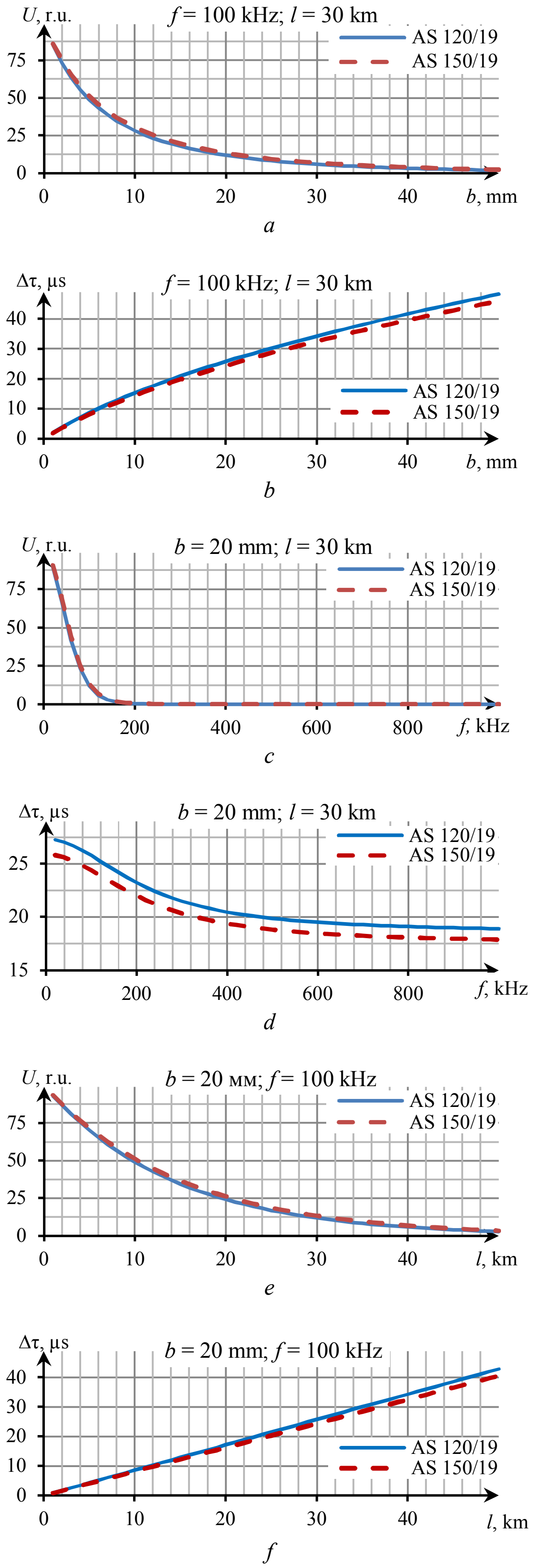

Figure 1. Correlation of amplitude U (*a*, *c*, *e*) and delay $\Delta\tau$ (*b*, *d*, *f*) of location signal from ice thickness deposition b (*a*, *b*); from the lengths of wires covered by ice deposition l (*c*, *d*); from frequency of pulsed probing signal f (*e*, *f*)

Besides, additional delays cause wires stretching due to the ice depositions weight and wind loads. However, they have little impact on total delay, thus they could be ignored. Signal attenuation increases due to reduction in wire diameter and augmentation of signal frequency (Figure 1, *c*), while delay is decreased when frequency grows (Figure 1, *d*). augmentation of ice thickness wall, and length of wires covered by ice leads to attenuation growth (Figure 1, *a*, *e*) and delays growth (Figure 1, *b*, *f*) of location signal. Linear dependence between delay index and length of ice coating (Figure 1, *f*) allows to bring lineal delay, which simplifies calculation of operating values for the lines with different length.

Hereinabove it was described definition of location signals parameters U and $\Delta\tau$ for ice deposition with the wall b and ice cover length l_{Ice} on wires OPL. In order to define ice walls using U and $\Delta\tau$ indexes it is necessary to solve inverse problem – i.e. finding system roots of two equations with two unknowns:

$$\begin{cases} U(b,l) = U_{Ice}; \\ \Delta\tau(b,l) = \Delta\tau_{Ice}. \end{cases}$$

Unfortunately, it is difficult to define walls thickness and ice length using parameters U and $\Delta\tau$ of the reflected signal because equation could have numerous solutions, as well as no solutions at all. Hence, l and b could not be determined uniquely. According to some observations, it is also necessary to record length of the area, most likely covered by ice depositions l, and then calculate thickness of ice walls by each of the parameters, thus defining range of possible values for ice thickness b.

Results of calculations using developed method, algorithm and computer program [5] to define U and $\Delta\tau$ by ice thickness b as of January 2013 are depicted on Figure 2. Maximum value of ice deposition equal to 3 mm was observed on January 4, 2013. Those ice depositions could not make any harm to the coherence of overhead power wires.

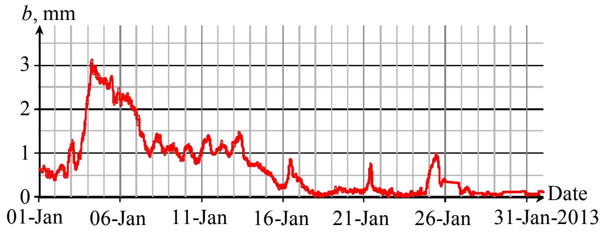

Figure 2. The location method to control thickness of ice depositions on 110 kV wires OPL within a month "K Bukash–R Sloboda" [1–31 Jan 2013]

As was already mentioned above, drawback of location method is failure to differentiate between slight-thickness ice deposition of the long overhead power line and dangerous concentration of ice on its separate small areas. The method of subdividing power lines into location segments with spotted imperfections is used to prevent this drawback.

Due to the spotted imperfections, it is possible to subdivide the 40 000 m "K Bukash–R Sloboda" line into 5 areas. Graph of ice thickness b behavior could be depicted for each of the line as shown on Figure 3.

By comparing dependence of ice thickness from time on different areas (Figure 3, blue curves) with the curve of average ice thickness values variations (Figure 3, dashed line), which was calculation without line-splitting, it is evident that ice thickness b (in mm) varies on different areas. It is obvious that maximum risk of wires breakage is observed at maximum values of b. Within the observation period, maximum wall thickness was recorded on the area between towers № 99 and 134 (7.12.2011), and minimum thickness value between № 40 and 99 (10.12.2011).

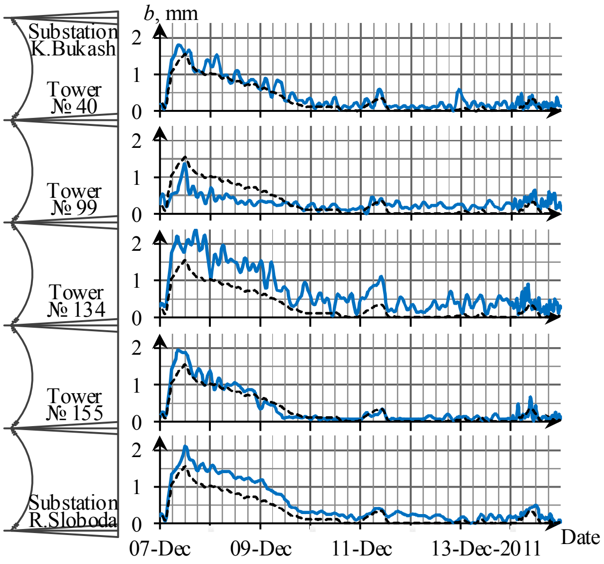

Figure 3. Time history of ice thickness *b* on "K Bukash–R Sloboda" line for five areas (blue curves) and for the whole line (dashed curve) [7–14 Dec 2011]

Figure 4 depicts graphs of ice thickness behavior along the "K Bukash–R Sloboda" line. The first two graphs show propagation of ice depositions, which started to be formed on December 30, 2013, and completely faded away on January 1, 2014. The first graph, calculated as of 19:00, December 30, 2013, corresponds to the maximum ice load per this icing incident. The thickest ice wall reached 2.9 mm value and was recorded on the 4th area (between towers №134-155). Later, ice coating started to come off from the wires, which corresponds to the moment of partial vanishing on second graph. As shown on 2nd graph Figure 4, ice thickness decreased along the most part of the line (except 2nd area): it decreased almost in half on the 4th area from 2.9 mm to 1.5 mm, however grew on the second area (between towers №40-99) from 2.5 mm to 2.8 mm.

The last two graphs on Figure 4 correspond to the icing incident as of January 11-12, 2014. Maximum values of ice depositions are indicated on January 11 at 21:40. Thickness of ice wall on the 4th area reached 4.1 mm value. Since then ice depositions started to decrease; in 2 hours ice thickness was reduced to 2.5 mm on the 4th area, though it stayed the same on 1, 3 and 5 areas. However, by 4:00 on January 12, 2014, the line was totally cleaned off the ice.

This method of line subdivision allows eliminating drawback of the location method, which is determination of integral ice thickness value along the whole line length. Thus, it will help to prevent accidents on small but highly affected to the icing areas.

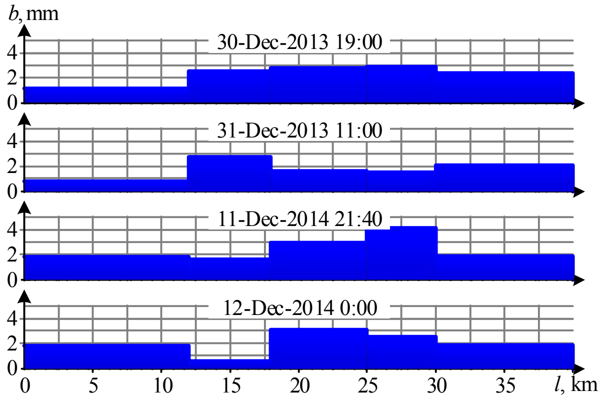

Figure 4. Propagation of ice deposition on wires along 110 kV line on "K Bukash–R Sloboda" line during different observation days

Given examples decisively demonstrate capabilities of the location method for ice deposition detection on OPL wires, and confirms its high sensitivity to earlier detection of ice coating, starting from 0.1 mm ice thickness and even less.

Algorithm, methodology and computer program to calculate thickness of ice coating deposition were developed and probe-tested in order to help estimating weight of ice-forming coupling in a span. If it exceeds allowed values, a signal to start ice melting is given. In the above mentioned cases, ice melting was not needed.

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