Multichannel radar monitoring of ice on power transmission lines

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***Abstract*: A unique technology and technique as radar method and ice detecting apparatus on overhead power transmission lines, which were firstly introduced in substations in Russia are represented here.**

Keywords: overhead power transmission lines, ice on the wires, ice location detection, measuring methods, radar equipment sets, systems operation, observation of ice deposits, advantage of radar detection of ice.

Legend and Abbreviations

KSPEU	*Kazan State Power Engineering University*
PTL	*Power Transmission Lines*

Currently, there are two ways of ice detection wires of PTL:

1) Forecasting the probability of icing on basis of meteorological data of environment around the wire, taking into account the technical parameters of transmission line.
2) Immediate control of icing with sensors and ice detection devices [1].

Ice forecasting based on meteorological environmental data, is used in many countries where icing on transmission lines is an urgent issue to mitigate or avoid its impact on effectiveness of these lines.

Formation of ice on wires on overhead lines depends on the climatic region and is subject to certain meteorological laws: depends on the humidity and ambient air temperature, wind conditions. Formation of ice also depends on wire diameter, suspension height, mounting inflexibility, twists on wire, current flowing through the load.

Unfortunately till now there is no specific model of ice deposit formation on power transmission lines, which can reliably take into account all these factors, so in such kind of forecast number of false alarms is sufficiently high. In addition, the forecast data may not be specifying indications at the beginning of ice melting, formed on the wires of overhead lines.

Now a days immediate control of icing on power transmission lines is being performed by two methods: method of weight sensors and radar sensing method.

The method of weight sensors is based on comparing the weight of the wires in a passage in absence and presence of ice deposits. The value of wire tension is determined by ice load, wind, as well as ambient temperature. Assessment of the stress state of the wire and comparing it with the maximum permissible value, are carried out with strain sensors. The sensors detect the weight of glaze deposits close to one pillar, their data is transmitted to the receiving station using means of remote control.

Radar detection method of ice on wires of power transmission lines is an alternative method of strain sensors. Radar method is being developed in the KSPEU over 15 years since 1998 [1]. This method is unique in the world according to all available information of last 40 years.

During this period of theoretical and experimental work, methods and sensing apparatus of power transmission lines have been developed, and methods of interpretation of results of sensing ice deposits detection have been established.

Formation of ice on wires represents as impure dielectric, reducing the speed of spreading signal along the line causes additional attenuation due to dielectric losses of electromagnetic wave energy that is consumed in heating of ice layer coating. Radar method allows to determine the occurrence of icing on a transmission line by comparing the propagation time of the reflected signals and their amplitudes in presence and in absence of ice formation.

To probe line with pulse radar (reflectometer), which is a simplified diagram of the connection to the line is shown in Figure 1, *a* totality of the reflected pulses forms a trace. The appearance of ice deposits on line causes a change in trace. If, from the standard (reference) trace (Figure 1, *b* – green line) to deduct the current trace (Figure 1, *b* – blue line), the difference changes are reliably detected by the appearance of a signal corresponding to the end of the line (Figure 1, *b* – red line). The more the characteristic impedance of the line will change under the influence of thickness of ice deposits due to changes of dielectric constant between the wires of the line, the more will be the difference between the traces, the more will decrease pulse amplitude ΔU and will increase pulse delay $\Delta\tau$ (Figure 1, *b*).

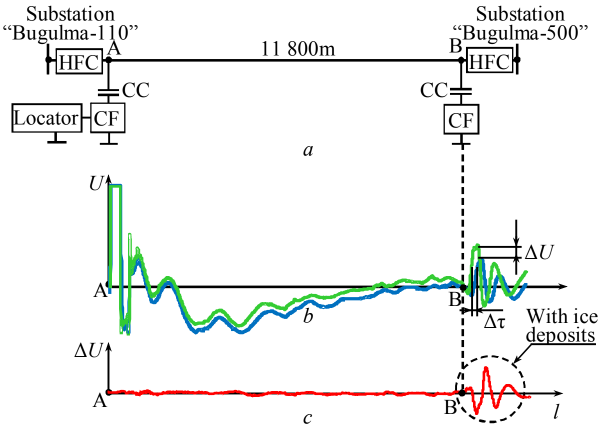

Figure 1. Detection of ice on the line 110 kV "Bugulma-110–Bugulma-500": a – line diagram; b – trace of line without ice (green line) and in presence of ice (blue line); c – difference (red line) line traces without ice and in the presence of ice with fluctuations in the signal at point B due to the presence of ice deposits (HFC – high-frequency choke, CC – coupling capacitor; CF – connection filter, locator - locating the device)

Figure 2 shows as an example of daily bases changes of amplitude *U* (top) and the delay $\Delta\tau$ (lower graph) of the reflected pulses of 110 kV PTL "K Bukash-R Sloboda".

In presence of ice deposits the amplitude U and delays $\Delta\tau$ change synchronously, as shown in Figure 2 (marked by dashed ovals). Using two criteria's U (or ΔU) and $\Delta\tau$ increase the reliability and accuracy of ice detection on wires of power transmission lines.

Except ice deposits, weather conditions, changes in ambient temperature (dashed line in Figure 3, the temperature scale on the right side of the figure), wind effects, and so on can effect on reading on amplitude U and reflected pulse delay $\Delta\tau$.

Hardware-software complex of ice monitoring system consists of the following components:

- radar sensing device;
- communicatation device;
- a computer with a wireless modem and operator interface;
- central server.

Commutation device is designed to connect output/input of radar with one of 16 wires of overhead transmission lines of substation.

The computer along with wireless modem and interface control the operation of radar device, transmit data to the central server, and form the operator interface.

The central server performs as an archiver.

Recently, employees of KSPEU designed and manufactured a small series of radar system for sensing power transmission lines, which are being successfully used to control icing on existing power transmission lines.

In 2012, employees of KSPEU together with employees of OJSC "Scientific-industrial enterprise "Radioelektronika" named after V.I. Shimko" by the order from OJSC "Federal Grid Company of Unified Energy System" designed, manufactured and tested a prototype of an autonomous and automatic ice monitoring system with 16 channels. The complex has a desk-wall mounted version as showed in Figure 3.

Control of icing on power transmission lines has been carrying out since 2009 in lines of 35-110 kV substation "Bugulma-110" (the Volga region), on lines of 110 kV substation "K Bukash" (Volga region), and from 2013 on lines of 110 kV substation "Shkapovo" (Ural) and on the lines of 330 kV substation "Baksan" (North Caucasus). The complex operates continuously in an automatic sensing mode and transmits data every 30 (60) minutes to the control center of KSPEU. Ice deposit data can be transmitted via GSM channel or internet to control room at any distance, providing a user-friendly interface to monitor the dynamics of icing and melting of ice on wires of power transmission lines.

In all substations preliminary diagnosis of condition of transmission lines was performed before control, defined their configurations, measured standard traces, identified channels and high-frequency interfering communication network, set probing mode and took measures to isolate reflected pulses of interference.

Currently in substation "Bugulma-110" radar complex is serving 7 power transmission lines, out of then six are of 110 kV and one in of 35 kV.

A schematic arrangement of controlled power transmission lines in relation with substation "Bugulma-110" is shown in Figure 4.

Figure 5 shows an example of changing parameters ΔU and $\Delta\tau$ of transmission line "Bugulma-110–Bugulma-500" for January 2011-2014.

According to Figure 5 largest ice formation was observed in 1 Jan 2014, when U decreased to 25 relative units, and $\Delta\tau$ increased to 2 microseconds. These values U and $\Delta\tau$ were below to critical, like others, so the melting of ice on power transmission lines "Bugulma-110–Bugulma-500" in the period under consideration did not happen.

As radar measurements are integral measurements, in same ice condition, ΔU and $\Delta\tau$ of long lines are overvalued in relation to short lines. Therefore, more objective parameters are specific

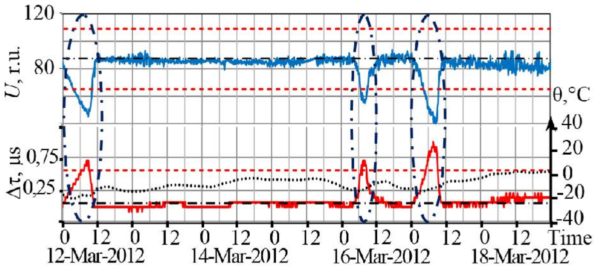

Figure 2. Daily bases change of amplitude U (top) and the delay $\Delta\tau$ (lower graph) of the reflected pulses of 110 kV power transmission line "K Bukash-R Sloboda"; ovals designated registration of ice formations [12.03-18.03.2012]

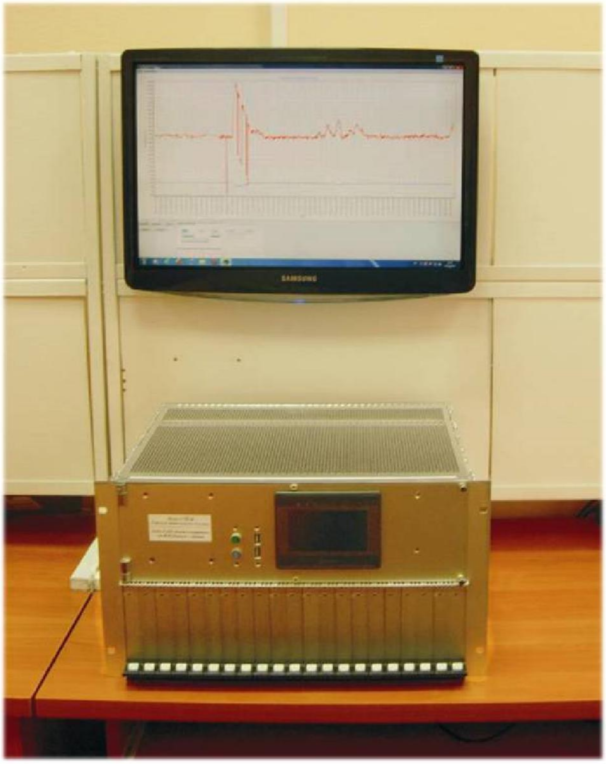

Figure 3. Desktop version of ice detection radar on power transmission lines with 16 wires [2012]

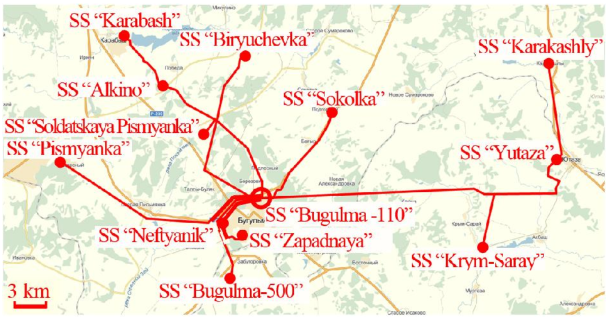

Figure 4. A schematic arrangement of seven power transmission lines of substation "Bugulma-110" controlled by radar complex

attenuation values δK (dB/km) and the delay $\delta\tau$ (μs/km), given to a unit length of the line, in this case length is 1 km.

Examples of multi-channel sensing results in substation "Bugulma-110" for the period November-December 2014 with measurements of specific values $\delta\tau$ are shown in Figure 6. According to the data of Figure 6 largest ice deposit was found

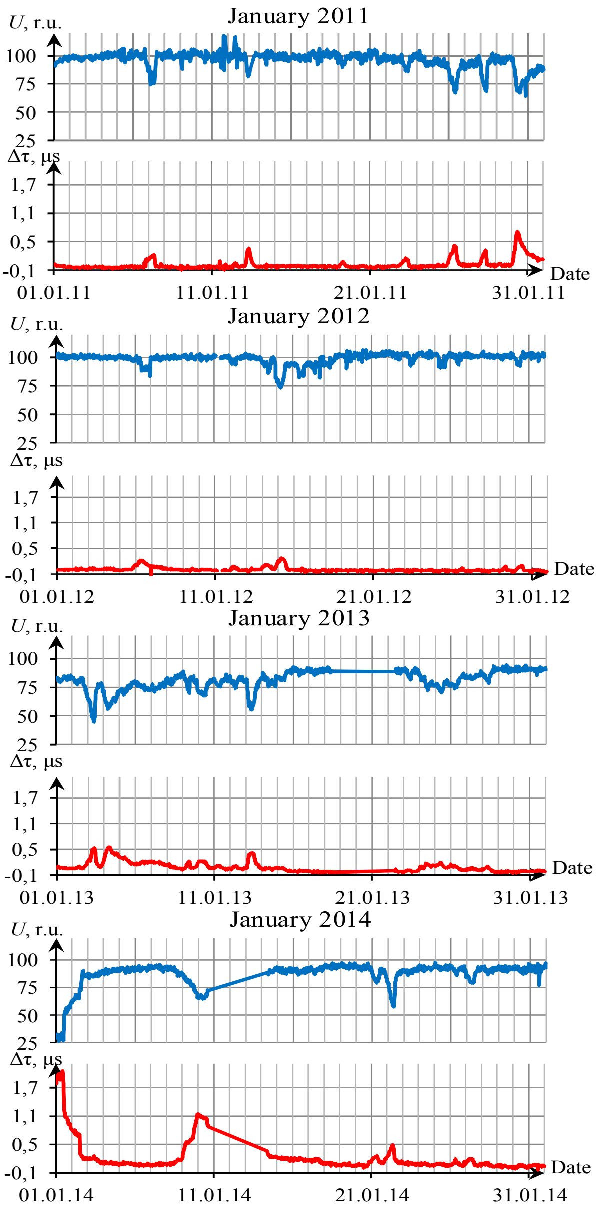

Figure 5. An example of change of the measured amplitude U and delay $\Delta\tau$ reflected radar signals in presence of ice deposits on transmission line "Bugulma-110–Bugulma-500" for January 2011-2014

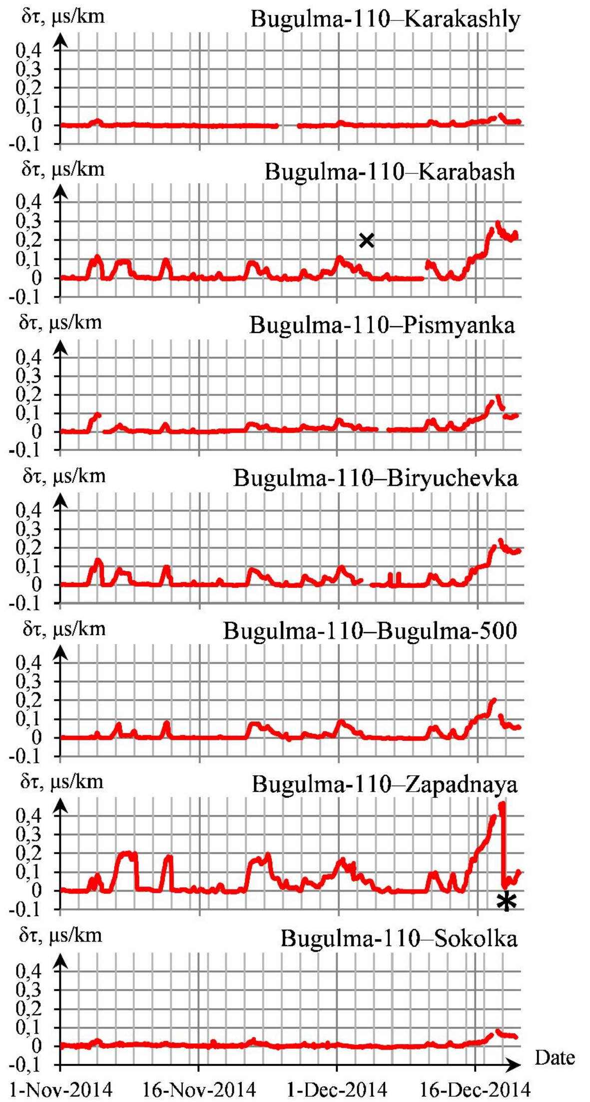

Figure 6. Example of changing the specific delay of reflected radar signals during formation of ice deposit on controlled transmission lines of substation "Bugulma-110" [1.11-20.12.2014]

on the line "Bugulma-110–Zapadnaya", where a breakage was made to prevent wire in December 18, 2014 , ice melting (marked *) at values δK = 1.2 dB/km and $\delta\tau$ = 0.48 μs /km.

Figure 7 shows a photograph of frost formation on wires of transmission line "Bugulma-110–Karabash" December 1, 2014 at 10 o'clock 16 minutes, which corresponded δK = 0.3 dB/km and $\delta\tau$ = 0.1 μs/km (snapping time is marked on Figure 6 with a cross). Naturally, this ice formation could cause breakings power line wires.

Thus, radar ice detection system has been developed and introduced into service to detect ice formation on the 35-330 kV overhead transmission lines. Complexes can reliably monitor the dynamics of ice formation on the wires and clearly define the beginning of time required for melting ice deposits in real time.


Figure 7. Frost formation on wire lines "Bugulma-110–Karabash" December 1, 2014 at 10 o'clock 16 minutes, which corresponded δK = 0.3 dB/km and $\delta\tau$ = 0.1 μs/km (snapping time is marked in Figure 5 with cross)

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