Modeling the influence of glaze-ice and rime deposits on the propagation of location signals through transmission lines

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Abstract— **The model of a high frequency (HF) baseband transmission path, implemented in the PSCAD software environment, is considered. This model allows to study distribution of locational signals over the wires of overhead power lines (OPL) under the conditions of formation of any ice coating on them. The calculated frequency dependences of the attenuation of the baseband transmission path of an overhead power line and the relative velocity of HF signal propagation along the baseband transmission path of the overhead power line for various wall thicknesses of an ice coating are given.**

Keywords— ***overhead power lines, glaze-ice and rime depositions, high frequency transmission lines, location method, simulation modeling.***

I. INTRODUCTION

Use of the method of locational probing of overhead power lines allows to identify any ice coatings on the wires [1]. HF communication organized using the wires of overhead power lines and intended for transmission of various technological information got widespread use in the Russian Federation. The locational probing equipment shall be connected parallel to the communication equipment to the existing high frequency channel organized using the wires of the power lines. For comparison of the results of locational probing, determination of the optimal parameters for the probing signal it is reasonable to design a model of a HF baseband transmission path that shall allow to take into account the effect of the ice coating to any change in the conditions of a probing signal propagation.

Propagation of an electromagnetic wave (impulse) along the line is a complicated process that depends on the number, the relative position, the material and the size of wires and ropes and their remoteness from the ground surface and on its electrical conduction. The basic problem in case of simulation of the probing signal propagation along the overhead power line under the conditions of ice forming is the following: parameters of the HF transmission line and the ice coating are often interdependent; earth resistance has a great effect on the signal propagation; ice coatings have various density.

In case of study of wave transient processes, the overhead power lines are considered as a long line with distributed parameters. The distribution of voltages and currents in time and distance in long lines is described by telegraph equations, which are a particular case of solving of Maxwell's equations. It should be noted that the telegraph equations do not take into account the irregularities of the design and sag of wires, as well as the proximity effect, the presence of insulating elements, the end effects and radiation.

II. FUNDAMENTALS FOR SIMULATION OF A HIGH FREQUENCY BASEBAND TRANSMISSION PATH IN PSCAD SOFTWARE ENVIRONMENT

In PSCAD software package, overhead power line models with lumped line parameters and with distributed parameters are implemented, the latter ones are divided into models with and without frequency dependence of the parameters.

The full list of overhead power line models that can be implemented in PSCAD includes the following [2]:

1. U-shaped model with lumped parameters, the parameters of which do not depend on frequency;
2. Bergeron model - a model with distributed parameters and with lumped loss resistances, the parameters of this model do not also depend on the frequency [3];
3. The frequency-dependent model of the line with distributed parameters and calculation in modal coordinates [4];
4. The frequency-dependent model of the line with distributed parameters and calculation in phase coordinates [5].

Wave transient processes in power lines cannot be analyzed using a model with lumped parameters (U-shaped model), in which the overhead power line is replaced by a set of passive elements (resistors, capacitances, inductances). The models with distributed parameters shall be used for this. Since video pulses having a wide spectrum are used as a probing signal of the locational complex the following frequency-dependent models shall be used: mode and phase model. Phase model is the most accurate one, because it takes into account the frequency dependence of the internal transformation matrices (thus, the model accurately describes both balanced and unbalanced systems). In a mode model, the transition from phase to modal coordinates is carried out using a transformation matrix, what introduces a certain error (up to 2%) in case of calculation of unbalanced systems. At that, it should be noted that a mode model has been repeatedly verified by various authors, and the industry standards for engineering communication using the HF transmission paths of power lines are developed on its basis [6]. It proves the fact that it is possible to use it for study of wave transient processes. Therefore, to simulate the propagation of location signals over the overhead power lines, we will use a mode model.

In the PSCAD software environment for the component overhead power lines (Tline library) it is impossible to take into account formation of ice coatings on the wires and on the ground wires of the overhead power lines. For this reason, the wires and the overhead ground-wire cables that form a HF baseband transmission path are represented in this model as coaxial cables located in the air above the ground. The presence of any icy coatings on the overhead lines is simulated by setting of the cable configuration, and namely by indicating of the presence of two “layers” - a conductor and a dielectric. At that, the basic electrical properties and geometric parameters of the conductor and the dielectric, as well as spatial location of the cables shall be set. Thickness of ice coating corresponds to the dielectric thickness (fig. 1),

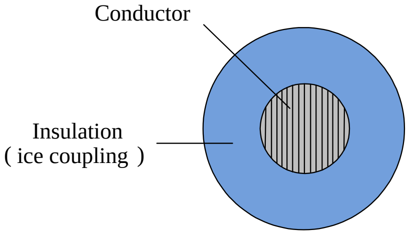

Fig. 1. Simulation of ice coatings on the wires and the overhead ground-wire cables of the overhead power line

Due to the functional limitations of the PSCAD software environment, the following assumptions were made in the process of ice coating simulation:

1. We assume that the line consists of parallel uniform circular conductors with a smooth surface that are parallel to the ground surface;
2. We ignore the proximity effect in the wires;
3. We ignore the active insulation conductance.
4. We do not take into account the influence of the end effect and radiation at the beginning and at the end of the line;
5. We do not take into account transverse currents in the ground;
6. The elongation of the wires of the overhead power lines under the influence of ice coatings is not taken into account.
7. The ice coatings are represented as an axisymmetric cylinder that evenly covers the wire of the line. At that, the length of an ice coating shall be taken as the length equal to the length of the wires of the overhead power line.
8. Changes in the parameters of the HF baseband transmission path due to changes in the sag of the wires and changes resulting from the losses that are introduced by the ground into the transmission path are not taken into account.
9. The relative dielectric conductivity shall be set only by use of the real part, respectively, the loss in the dielectric layer shall not be taken into account.

This assumption can result in a significant error in the model. Therefore, the losses in the ice coating will be taken into account by increasing the resistance of the wires of the overhead lines.

Figure 2 shows the frequency dependences of the real part of the relative dielectric conductivity of ice with the density of ρ 0.9, 0.6, 0.3, 0.15 g / cm^3 on the signal frequency (16 kHz - 1000 kHz). As can be seen from fig. 2, the real part of the relative dielectric conductivity of ice depends on the frequency, but within the frequency range from 400 kHz to 1000 kHz it remains constant and for the density of 0.9 g / cm^{3}ε ' it is equal to 3; for 0.6 g / cm^{3}ε ' it is equal to 2.27; for 0.3 g / cm^3 ε ' it is equal to 1.6; for 0.15 g / cm^{3}ε ' it is equal to 1.3.

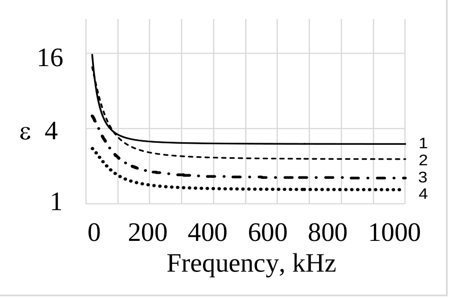

Fig. 2. Dependence of the signal frequency *f* of the real part of the dielectric conductivity GIO ε' with the density of ρ 0,9 (1), 0,6 (2), 0,3 (3), 0,15 (4) g/cm^3 (u = 10, θ = 0 °C)

III. Verification of the High Frequency Baseband Transmission Path Model

Taking into account these assumptions, it was decided initially to compare the results of the calculation of the attenuation and the relative velocity of HF signal propagation in the presence of ice coatings with the results obtained using another software product that was tested, debugged, approved and verified in the process of designing, adjustment and operation of the HF communication channels, relay protection, etc. The comparison of the calculation results will make it possible to determine the limits of the reliability of the model implemented in the PSCAD software environment.

WinTrakt program is one of such software products. In the Russian Federation, this software product is recommended for calculation of the high frequency transmission lines organized along the overhead lines with voltage of 35-750 kV [6]. It should be noted that the WinTrakt software environment allows to calculate efficiently and reliably enough the high frequency transmission lines when designing the HF communication channels, relay protection and emergency automation with calculation of the amplitude-frequency characteristics, the group delay time and any other parameters, but it does not allow to simulate the propagation of the location signals along the high frequency transmission lines, calculate and build reflectograms that are required in our case

In the WinTrakt software environment, the frequency dependences of the attenuation of the baseband transmission path of the overhead power line and the relative velocity of the HF signal propagation along the baseband transmission path of the overhead line in case of presence of ice coatings with various wall thicknesses of the coupling were calculated. The calculations are carried out for the overhead power lines with voltage of 110 kV. The power lines of this voltage class were selected because the fabricated experimental sample of the location complex controls eight overhead lines with voltage of 110 kV. The use of a single wire-to-ground circuit for connecting of a location device allows to extrapolate the results obtained for 110 kV overhead lines in the line of other voltage classes.

Figure 3 shows the calculated frequency dependences of the attenuation of the baseband transmission path in the absence (curve 1) and in the presence of ice coating (curves 2-6) for the overhead lines with voltage of 110 kV.

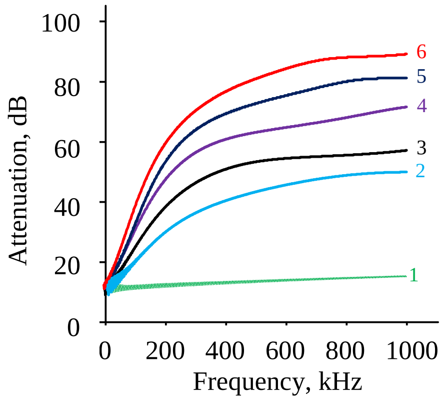

Fig. 3 The calculated frequency dependences of the attenuation of the baseband transmission path of an overhead line with voltage of 110 kV and the length of 30 km in the absence of (1) and in the presence of ice coating with wall thickness of: 2 – 10 mm, 3 – 20 mm, 4 – 30 mm, 5 – 40 mm, 6 – 50 mm (WinTrakt)

After analysis of the dependence shown in fig. 3 we can draw the following conclusions:

1. Increase of the wall thickness of the ice coating results in increase of attenuation.

2. The highest attenuation occurs at the frequencies of more than 400 kHz;

3. Attenuation increase will be decreased with increase of the ice coating wall thickness, for example, at the frequency of 200 kHz, attenuation in case of absence of any ice coatings is 12 dB (when an overhead line length is 30 km), when the wall thickness of the ice coating is 10 mm - 30 dB, 20 mm - 38 dB, 30 mm - 48 dB, etc.

Figure 4 shows the calculated frequency dependences of the relative group velocity of HF signal propagation along the HF baseband transmission path in the presence of ice coating for overhead lines with voltage of 110 kV.

As can be seen from fig. 4, the propagation velocity of the HF signal decreases with increase of the wall thickness of the ice coating, at that it does not almost depend on the frequency in the frequency range from 200 kHz to 1000 kHz.

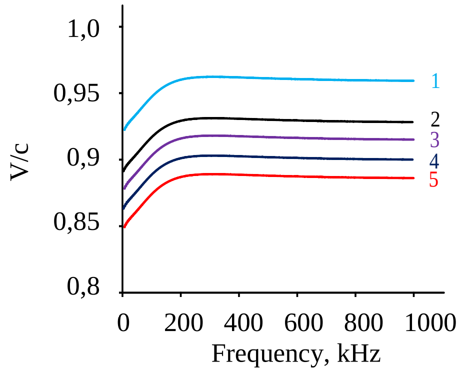

Fig. 4. The calculated frequency dependences of the relative velocity of the HF signal propagation along the baseband transmission path of a 110 kV overhead power line in the presence of ice coating with the wall thickness of: 1 – 10 mm, 2 – 20 mm, 3 – 30 mm, 4 – 40 mm, 5 – 50 mm (WinTrakt)

Due to the fact that the formation of ice coating has effect only on the change in the parameters of the HF baseband transmission path, in the PSCAD software environment we shall model only the power line. At the beginning of the baseband transmission path, we shall connect a generator with sinusoidal signal and with the output resistance of 50 Ohm, as in the computed model implemented using the WinTrakt program, and we shall connect matched load of 450 Ohm to the end of the line. For evaluation of the attenuation value and the change in the group time of the HF signal propagation, we shall use two oscillographs Ea0 and Ea1, connected at the beginning and at the end of the HF baseband transmission path (Fig. 5).

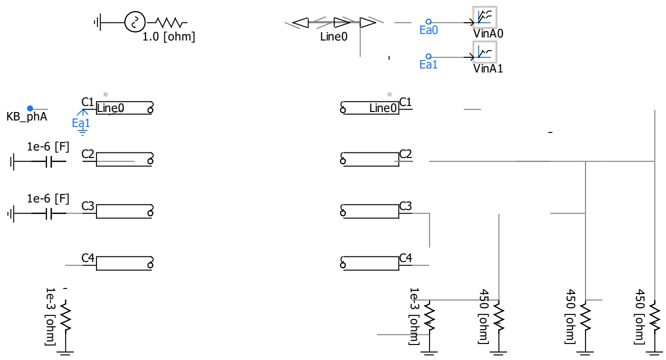

Fig. 5. Model of the HF baseband transmission path of an overhead power line with voltage of 110 kV, implemented using the PSCAD software environment

As a result of the analysis of the calculation results for the primary line parameters (intrinsic and mutual resistances of the wires, intrinsic conductivity and transfer conductance between the wires — Z and Y matrices) and the frequency dependences of attenuation and signal propagation velocity along baseband transmission path for reducing of the model error implemented using the PSCAD software environment, it was decided to take into account the heat loss of the ice coating. It can be done using two methods: by increasing of the resistivity of the wires of the overhead line - in this case, at the expense of skin effect, we obtain a frequency-dependent increase in attenuation; or by introducing of an additional non-frequency-dependent longitudinal resistance, which value will depend on the length and on the wall thickness of the ice coating.

The obtained results of the calculated frequency dependences of the attenuation of the baseband transmission path of the overhead line with voltage of 110 kV for the first method are represented in Fig. 6, for the second method - in fig. 7 The length of ice coating is 30 km (covers the entire line), the wall thickness of the ice coating is 10 - 50 mm with the interval of 10 mm.

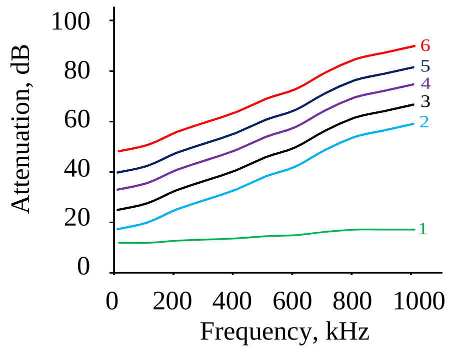

Fig. 6. The calculated frequency dependences of the attenuation of the baseband transmission path of an overhead line with voltage of 10 kV and the length of 30 km in the absence of (1) and in the presence of ice coating with wall thickness of: 2 – 10 mm, 3 – 20 mm, 4 – 30 mm, 5 – 40 mm, 6 – 50 mm (PSCAD – method 1)

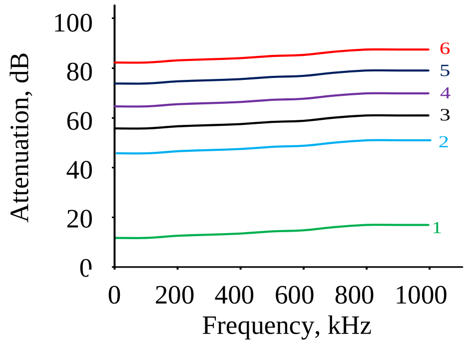

Fig. 7. The calculated frequency dependences of the attenuation of the baseband transmission path of an overhead line with voltage of 10 kV and the length of 30 km in the absence of (1) and in the presence of ice coating with wall thickness of: 2 – 10 mm, 3 – 20 mm, 4 – 30 mm, 5 – 40 mm, 6 – 50 mm (PSCAD – method 2)

Fig. 8 shows the calculated frequency dependences of the relative velocity of HF signal propagation along the baseband transmission path of the overhead line with voltage of 10 kV under the conditions of the presence of ice coating the length of which is 30 km (covers the entire line) in case of different wall thicknesses of the ice coating of 10 - 50 mm with the interval of 10 mm.

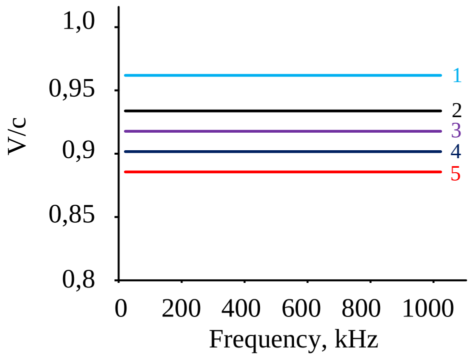

Fig. 8. The calculated frequency dependences of the relative velocity of the HF signal propagation along the baseband transmission path of a 110 kV overhead power line in the presence of ice coating with the wall thickness of: 1 – 10 mm, 2 – 20 mm, 3 – 30 mm, 4 – 40 mm, 5 – 50 mm (PSCAD)

Conclusions

Analysis of the calculated frequency dependencies obtained using the PSCAD software environment for overhead lines with voltage of 10 kV and their comparison with the calculated frequency dependence obtained using the WinTrakt program shows that:

1. Within the frequency range from 400 kHz to 1000 kHz, the second method is a more accurate method for taking into account the losses in the layer of ice coating (introduction of non-frequency-dependent longitudinal resistance);
2. The relative velocity of the HF signal propagation for PSCAD model does not depend on the frequency.

Thus, the assumptions accepted in the mathematical model implemented using the PSCAD software environment make it possible to use this model within a limited frequency range from 400 kHz to 1000 kHz. Therefore, for comparison of the model reflectograms obtained using the PSCAD software environment and the reflectograms obtained as a result of a physical experiment, a digital filter with the bandwidth of 400–1000 kHz shall be used in the process of data processing.

Similar dependences can be obtained for overhead power lines with other voltage class.

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