Methods of use of climatic conditions data for assessing climatic loads for OHL

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SUMMARY

Today in Russia there is in use a set of methods for assessing climatic loads for overhead transmission lines (OHL) based on data of climatic conditions. Gathering of climatic conditions data (hydrometeorological information) has been processed within the meteorological stations network that covers all the territory of the Russian Federation. These methods allow regional climatic maps creation, climatic loads assessment (including climatic loads having different return period) as well as providing the possibility to take into account transmission line length during calculation of design climatic loads.

KEYWORDS

Climate – design – criteria – method – load - transmission line – ice – wind

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**Climatic loads and assessing methods.**

The reliability and power transmitting capability of power network objects, such as overhead transmission lines and high-voltage substations, directly depends on design climatic loads. The values of design climatic loads determine selection and design of components of the transmission line, such as tower type, conductor type, span length, etc.

Inaccuracy in climatic loads assessment may lead to accidents on transmission lines with power transmitting capability losses and possible regional power outages.

Main loads that determine the planning of transmission lines are wind pressure on conductors and towers, weight of ice on transmission line components and their combined action.

Nowadays in Russia there is a set of methods for assessing climatic loads for OHL based on data of climatic conditions:

- Method for processing of climatic conditions data;
- Method for creation of regional climatic maps;
- Climatic loads assessment method based on Russian standard;
- Method for assessment of climatic loads with different reliability level depending on voltage of OHL, its responsibility and owners demands;
- Method for assessment of climatic loads depending on line length.

On the figure 1 below is represented the scheme of design climatic loads assessment. Further in the article is described every one of the methods above-mentioned.

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**Figure 1 – Scheme of design climatic loads assessment**
Method for processing of climatic conditions data.

All the above-mentioned methods are based on meteorological information collected on the meteorological stations network that covers all the territory of the country. Today nearly 2000 meteorological stations perform observations on meteorological conditions.

Wind speed and direction are measured on weather-vane or wind meter at 10 m height above the ground. Observations on the wind meter (anemometer model M-63) averaged over 10 minutes, on the weather-vane – 2 minutes.

Ice observations on meteorological stations are performed using a special designed device (icing device). This icing device consists of four cables of 5 mm in diameter, fixed in pair towards meridional and latitudinal directions and suspended at the two different heights of 1,9 and 2,2 m above the ground for each pair. For every icing event are measured size of ice accretion, its weight and type (glaze ice, hard rime, etc.). During every icing event are also measured other meteorological parameters, such as air temperature, wind speed and direction.

The meteorological stations network in the territory of the Russian Federation has carried on mass observations of icing events since 1951. Today’s observations of icing events are performed by 1254 meteorological stations all over the territory of Russia. The period of instrumental observations reaches today 58 years, and for some stations even beyond.

Data concerning all observations done by meteorological stations are collected and stored by the National Meteorological Service (Rosgidromet).

Long-period observations data collected on every meteorological station is used to create statistical arrays on the base of yearly maximums. These arrays should be of homogeneous data. In practice, the data often do not match the demand of homogeneity, this could be because of:

- Meteorological station transfer to a new place;
- Meteorological instruments substitution;
- Modifications of observations time quantity;
- Shading of meteorological station instruments by various objects.

**Meteorological station transfer to a new place**

In case of meteorological station transfer to a new place, it is advisable to analyse every part of statistical array separately.

**Meteorological instruments substitution**

Such modification refers to the substitution of the former wind measure instrument having averaged period of 2 minutes, to the modern anemometer model M-63 having averaged period of 10 minutes. This is why the old data should be converted to the values averaged over 10 minutes.

**Modifications of observations time quantity**

Before 1966 there were 4 observations times done every 24 hours, after this date observations became 8 times. To remove the influence of such modification on measured data, we use special coefficients in order to bring all measured data to the condition of so-called “continuous measurements”.

**Shading meteorological station instruments by various objects**

Shading of meteorological instruments by various types of objects (buildings, trees and etc.) could significantly influence measurements by reducing obtained values. The processing of data to the “conditions of open territory” is made in the following way:

- For wind measurements is applied a coefficient that depends on wind direction and indicates shading of instrument for wind measurements;
- For icing measurements is applied:
  a. Coefficient that depends on the height of the object shading icing device and of the distance to it;
b. Coefficient that depends on the angle between wind direction and the conductor installed on the icing device.

After applying all the above-mentioned procedures, statistical arrays are processed to the conditions of standard transmission line. When referring to standard transmission line we mean line having conductor with a diameter of 10 mm that is suspended 10 m above the ground.

Maximum values (wind speed, equivalent radial ice thickness, combined ice-wind load and maximum wind speed for icing event) corresponding to every year (cold season) of measurements and called yearly maximum are used to create statistical arrays for every considered meteorological station.

For every statistical array we calculate the following statistical parameters: mean value, standard deviation and coefficient of variation.

To describe the distribution of statistical arrays it is used Gumbel distribution law:

\[ F(x) = e^{-e^{-\alpha(x-\beta)}} \]  \hspace{1cm} (1)

For those cases when statistical arrays cannot be described by a Gumbel law we use other statistical laws:

- Fisher-Tippet distribution law:

\[ F(x) = e^{-\left(\frac{x}{\beta}\right)^\gamma} \]  \hspace{1cm} (2)

- Distribution with cumulative distribution function:

\[ F(x) = e^{-Ae^{\left(\frac{x}{\gamma}\right)^\gamma}} \]  \hspace{1cm} (3)

In the formulas above: \(x\) – variable, and \(\alpha, \beta, \gamma, A\) – parameters of distribution function.

Values of climatic loads having certain exclusion limit are calculated by using one of those distribution laws.

In order to obtain reliable values of climatic loads the period of meteorological observations should be more than 30 years. If not, such data could be used as subsidiary data during the process of icing map creation.

**Method for regional climatic maps creation**

The use of regional icing maps of wind speed, equivalent radial ice thickness and ice-wind load allow the assessment of wind-, ice- and ice-wind loads. Regional maps provide a visual representation of the distribution of climate parameters in a given territory.

*Using past experience with existing OHL.* For creating regional climatic maps we use past experience data of OHL located in the region. This means we utilize observations made on OHL conductors during line operation.

The major requirement to past experience data is the availability of reliable measurements of icing weight or its size and exact identification of its type or density [1]. It is also essential that measurements refer to a particular geographic point (geographic coordinates and altitude). It is worthy to compare past experience data with observations of the nearest meteorological station.

Information on icing size and weight are collected for the entire operating period of the line.

Currently, we have two different ways of using past experience data:

- The first way employs information on size and weight of icing, collected for the entire operating period of the line. The data is ranked in ascending
order and one of the statistical law is used to describe the distribution and to obtain
the value of the ice load having a certain return period;

- The second way uses the maximum value of the ice load observed
during the entire operating period. This maximum of the ice load is used to obtain
the value having a certain return period by implementing empirical dependence.

**Terrain influence.** The regional and local topography (the relief) is one of the most
important factors affecting spatial distribution of climatic loads all along the territory [2].
Depending on the morphometry of the relief (height above sea level and relative heights) it is
defined the kind of large-scale relief type – plain or height (hill). Considering main wind
directions it is possible to distinguish different subtypes of large-scale relief: windward or
leeward sides of heights, and valleys exposed or valleys closed for the main wind directions.

The map of types and subtypes of large-scale relief is then created.

**Regional climatic maps.** For types and subtypes of large-scale relief we build a graph of
functional dependence of climatic characteristic (wind speed, equivalent radial ice-thickness,
ice-wind load, maximum wind speed for icing event) from the height above sea level. The
dependence is \( x=f(H) \) (where \( x \) – value of climatic characteristic, \( H \) - height above sea level)
and is built considering local small-scale relief. In Russia for the break down of territory we
use climatic characteristics having a return period of 25 years.

For the break down of the territory into wind regions we distinguish 8 regions with
normative wind pressure (wind speed) from 400 Pa (25 m/s) to 1500 Pa and more (49 m/s and
more).

For the break down of the territory into icing regions we distinguish 8 regions with
equivalent radial ice thickness from 10 to 40 mm and above. Gradation range of the region is
5 mm.

For the break down of the territory into ice-wind load regions we distinguish 9 regions
with the value of ice-wind load from 3 to 28 N/m and above. For every ice-wind load region it
is specified the wind speed having a return period of 25 years and a conventional equivalent
radial ice-thickness.

**Climatic loads assessment method based on Russian standard**

According to current Russian standard design loads are obtained on the base of
normative climatic conditions. Normative climatic conditions are calculated using regional
climatic maps on wind pressure, equivalent radial ice thickness and ice-wind load or
calculated by using measurements for a long period made on meteorological stations [3].

To obtain normative wind load it is used a normative wind pressure \( W_0 \), which is
calculated on wind speed \( V_0 \) having return period of 25 years and averaged over 10 minutes.

Normative wind pressure \( W_0 \), Pa (normative wind speed \( V_0 \), m/s) vary from 400 Pa (25 m/s)
in the I° normative region to 1500 Pa (49 m/s) in the VII° normative region. It is called
“special region” if wind pressure exceeds 1500 Pa. In this case the wind pressure that is used
is rounded to the value divisible by 250 Pa.

To obtain normative ice load it is used a normative ice thickness \( b_e \), mm, with density of
0.9 g/cm\(^3\) on a conductor with a diameter of 10 mm that is suspended 10 m above the ground.

Normative ice thickness \( b_e \) vary from 10 mm in the I° normative region to 40 mm in the
VII° normative region. It is called “special region” if ice thickness exceeds 40 mm. In this
case the value is used as it is.

To obtain normative ice-wind load it is used the value of the wind load on the iced
conductor with a diameter of 10 mm that is suspended 10 m above the ground.

Normative ice-wind load \( P_w \) vary from 3 N/m in the I° normative region to 28 N/m in
the VIII° normative region. It is called “special region” if ice-wind load exceeds 28 N/m. In
this case, the normative ice-wind load that is used is rounded to the value divisible by 5 N/m.
For every ice-wind load region are also shown the following climatic parameters:
- Wind speed during icing event having return period of 25 years;
- Conventional icing diameter.

Design climatic loads are calculated on the base of normative climatic loads (wind load, ice load, ice-wind load) by applying coefficients of: responsibility (from 1.0 to 1.3), reliability (1.1, 1.3; 1.6), operating conditions (0.5; 1.0) and regional (from 1.0 to 1.5).

**Method for assessment of climatic loads with different reliability level depending on voltage of OHL, its responsibility and owners demands.**

This method has been developed based on IEC [4] and CIGRE [5] recommendations. It allows obtaining climatic loads depending on chosen reliability level from 0.96 to 0.998 (see table 1).

<table>
<thead>
<tr>
<th>Transmission line voltage, kV</th>
<th>Recommended reliability level</th>
<th>Reliability, $P$</th>
<th>Return period, $T$, years</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤1</td>
<td>I</td>
<td>0.96</td>
<td>25</td>
</tr>
<tr>
<td>35</td>
<td>II</td>
<td>0.98</td>
<td>50</td>
</tr>
<tr>
<td>110</td>
<td>III</td>
<td>0.99</td>
<td>100</td>
</tr>
<tr>
<td>220</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>330</td>
<td>IV</td>
<td>0.993</td>
<td>150</td>
</tr>
<tr>
<td>500</td>
<td>V</td>
<td>0.998</td>
<td>500</td>
</tr>
<tr>
<td>750</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Reliability level selection is done considering OHL voltage, its responsibility and owner demands.

Design climatic loads of chosen reliability are calculated on the base of climatic conditions having reliability of 0.96 (return period of 25 years) by applying special coefficients corresponding to selected reliability level. These in turn are obtained from regional climatic maps or by using measurements for a long period collected from meteorological stations and past experience on OHL.

**Method for assessment of climatic loads depending on line length.**

Climatic conditions and loads, calculated according to the methods above-mentioned, are valid for every point of the territory or OHL. When designing OHL, it is usually assumed that these conditions are valid for the entire line. But the overhead transmission line is an object extended in space, and climatic conditions change along its extension and in time. So return period and quantity of cases of overloading will differ for the entire line from that one of a single point. This is why the above-mentioned assumption leads to the underestimation for the entire OHL of the probability of occurrence of the climatic load exceeding design load. This is particularly true for the transmission lines with a length of more than 100 km.

For transmission lines having length more than 100 km, it has been developed a method that takes into account characteristics of atmospheric processes of the considered territory. In this method it has been introduced the concept of “exceeding zone”. This “exceeding zone” describes synoptic processes. In every point of this zone measured load exceed existing design load.

Climatic conditions are connected with atmospheric processes. Cases of overloading in different parts of the line are caused by different trajectories of the exceeding zones. The size ($\Theta$) of exceeding zone depends on physical geographical conditions of the territory and on the characteristic of synoptic processes.
The size \( (\Theta) \) of exceeding zone is calculated based on quantity \( n \) of cases of overloading for OLH by using formula

\[
\Theta = \frac{l}{n-1},
\]

(4)

Where \( l \) – line length, km.

Quantity \( n \) of cases of OHL overloading is calculated based on meteorological stations observations and on past experience with existing transmission lines.

Reliability of the entire line \( (\varphi) \) is calculated by using the formula

\[
\varphi = (1 - P')^{\frac{l}{\Theta}}
\]

(5)

Where \( P' \) – exclusion probability for the point of the line.

When we have the parameters of the size of the exceeding zone \( (\Theta) \) and of the desired reliability of the entire line \( (\varphi) \), we can calculate the reliability in every given point of the transmission line \( (P')\):

\[
P' = 1 - \varphi^{\frac{l}{\Theta}}
\]

(6)

Hence, using this method it is possible to obtain the reliability for the entire line based on the exclusion probability for the single point of the line. And vice versa, if specifying desired reliability for the entire line it is then possible to calculate necessary reliability for every point of the OHL.

**BIBLIOGRAPHY**

[1] V.A. Lugovoi, L.V. Timashova, S.V. Chereshnyuk “Assessment of climatic loads for overhead transmission lines” (Electric stations, number 8, 2004, pages 75-80) (in Russian)


