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/ Challenges & new solutions in design and construction of new OHL

Selection system of high-voltage external insulation for a.c. and d.c. overhead lines on the basis pollution mapping

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SUMMARY

The paper summarizes the main criteria and approaches of the present-day Russian pollution level mapping (PLM) system for selection of external insulation of DC and AC electric installations operating in contaminated and humidified conditions at operating voltage. Over the past 30 years PLMs were made for many countries with different climatic conditions: Russia, Cuba, Egypt, Mongolia, Estonia, Kazakhstan, Turkmenistan.

PLM is a special geographic map, containing marked industrial and natural sources of pollution, electric equipment (overhead lines (OHL) and substations), contours, showing areas with identical pollution levels, taking into account the impact of atmospheric boundary layer pollution on reducing the dielectric strength of electrical equipment (OHL and outdoor switchgear) insulation.

The determination of pollution level for OHL and substation outdoor switchgear sites allows the selection of insulation levels, since pollution level (PL) corresponds to a normalized value of specific creepage distance λ.

When selection of the optimal levels of outdoor insulation with use of PLM, the following factors should be taken into account:

- the completeness of the use of the creepage distance for insulators with a complicated construction;
- operation of insulators in composite structures;
- location of electrical installations at an altitude of more than 1000 m above sea level;
- less contamination of polymer insulators under natural conditions in comparison with glass and porcelain insulators;
- the difference in the magnitude of AC and DC voltage discharge.

Modern methodology for selection of insulation levels of DC and AC overhead lines using mathematical statistics methods when developing regional and local for areas with natural and industrial pollution sources allows choosing external insulation levels of DC and AC electric installations with required (specified) reliability (the number of overlaps), but without excess margins.

KEYWORDS

Overhead line, insulators, natural investigation, mapping methodology, pollution level.

1. INTRODUCTION

First technical guidance document regulating the mapping of pollution levels (PL) was developed in 1977 [1]. This document made it possible to begin developing the pollution mapping methodology in Russia and abroad. With the accumulation of new data, this document was improved and its new editions were released [2, 3, 4], studies were conducted in the power systems and, accordingly, pollution level maps were developed for the entire territory of Russia.

The call for developing the pollution level maps was caused by the fact that Russia occupies a vast territory (length from north to south exceeds 4000 km, and from west to east almost 10.000 km) with the most diverse sources of natural pollution (oceans, seas, salt lakes, saline soils) and human-made air pollution (emissions of plants of a wide variety of industries).

It was necessary to regularize and correlate various approaches and methods for selection of outdoor insulation of electrical installations [5] - [17]. The pollution level maps had proven to be most effective tool for solving these problems.

Each zone on the map with a defined PL index corresponds to the specific creepage distance value (λ) (the insulator creepage distance (L) per 1 kV of phase operating voltage).

2. THE APPROACH FOR NORMALIZING OF OUTDOOR INSULATION LEVELS

As a result of summarizing the operating experience of electrical installations, calculations and researches, analysis of bibliography on the subject under consideration, the following practical approaches have been accepted:

1. The outdoor insulation is selected for normal service conditions, i. e. for exposure of wet and polluted insulation to operating voltage stresses.

2. Pollution level is a quantitative characteristic of the effect of pollution and wetting conditions on the functioning of outdoor insulation at the site of the electrical installation; determination of pollution level is the main task when selecting outdoor insulation.

3. The specific creepage distance λ (cm/kV) is taken as the main parameter for normalizing the outdoor insulation levels of electrical installations (overhead lines and switchgears). Knowledge of λ allows to determine directly the dimensions of the outdoor insulation of electrical installations and, first of all, the creepage distance L (cm) by following expression:

$$L = U_{phмax} \cdot \lambda \cdot К, \tag{1}$$

where $U_{phмax}$ - electrical installation maximum phase operating voltage; λ is determined depending on PL and $U_{phмax}$ according to Table 1; K is the resulting factor correcting the creepage distance for insulating multiple structures made up of insulators of the same type.

According to the operating conditions of the insulation, four PL are established: 1 - light; 2 - average; 3 - strong; 4 - very strong.

The minimum λ values for porcelain, glass and polymer insulators of electrical installations (OHL and switchgears) operating at altitudes not higher than 1000 meters above sea level, depending on PL, are given in Table 1 separately for systems with insulated neutral (6–35 kV) and an effectively grounded neutral (110–750 kV).

Table1 – Minimum specific creepage distance λ of overhead lines insulators and switchgear outdor insulation [4]

PL	λ, cm/kV (not less than), at nominal voltage, kV	
	up to 35 and including	110÷750
1	1.9	1.6
2	2.35	2.00
3	3.0	2.50
4	3.50	3.10

For systems with isolated neutral λ approximately 20% higher than for systems with grounded neutral, which takes into account the long-term increase in operating voltage(approximately by √3) on healthy phases during a single-phase short circuit.

Given in Table 1 values of λ for various PL are interconnected - with an increase in the PL by one degree the required specific creepage distance increases by approximately 25%. Such an increase in insulation levels in many cases is sufficient to ensure acceptable operational reliability of outdoor insulation under pollution conditions, since the specific number of outages (the number of outages per 100 km of overhead line per year) due to flashovers of contaminated insulation is reduced by an order.

Creepage distance *L* of insulators and insulating structures of various configurations (including special configurations) are determined taking into account the correction factors by the expression

$$K = K_L \cdot K_к \cdot K_h \cdot K_p, \tag{2}$$

where

K_L – correction factor making allowance for structural features of special configuration insulators;

K_k – correction factor making allowance for the shape of a multiple-unit insulating structure;

K_h – correction factor making allowance for location of electrical installations at altitudes higher than 1000 meters above sea level;

K_p – correction factor making allowance for different pollution resistance of different insulating materials.

The values of these factors are given in Tables 2-7.

Factors K_L for suspension cap-and-pin insulators with weakly and moderately ribbed bottom surface ($0.9 < L/D < 1.4$) are found from Table 2 according to the ratio of the geometrical creepage distance *L* to the cap diameter *D*.

Table 2 – Factors K_L for suspension cap-and-pin insulators with weakly and moderately ribbed bottom surface [4]

L/D	K_L
From 0.90 up to 1.05	1.0
Over 1.05 up to 1.10	1.05
Over 1.10 up to 1.20	1.10
Over 1.20 up to 1.30	1.15
Over 1.30 up to and including 1.40	1.20

The factor K_L for suspension cap-and-pin insulators intended for heavy pollution areas is found from Table 3.

Table 3 – Factors K_L for special-purpose suspension cap-and-pin insulators

Insulator profile	K_L
Double wing	1.20
Antifog cap-and-pin insulator	1.25
Aerodynamic (hemispherical and conical)	1.0
Bell-shaped (smooth inside and ribbed outside surface)	1.15

In the case of external insulation in the form of single insulating structures (apparatus covers, post insulators, long-rod insulator units, bushings), the values for K_L are found from Table 4 using the ratio between the creepage distance *L* and the length of the insulating body *h*.

Table 4 – Factor K_L for apparatus covers, post insulators, suspension rod units, bushings [4]

L/h	under 2.0	2,5 - 3,0	3,01 – 3,30	3,31 – 3,50	3,51 – 3,70	3,71 – 4,00
K_L	1.0	1,1	1,15	1,20	1,25	1,30

The factor K_L for line and post pin insulators is taken to be 1.0 at a low profile and 1.1 at a high one.

The values for K_k are specified by the Russian standards as follows:

- K_k = 1.0 for I-strings of suspension cap-and-pin and rod insulators and for single stacks of identical post insulators;
- K_k is taken from Table 5 for multiple-unit structures with electrically parallel arms without jumpers (double and multiple supporting and tension strings, double and multiple stacks);
- K_k = 1.0 for Δ and V strings with single arms;
- K_k = 1.1 for multiple-unit structures with series-parallel single arms (Y and A strings, stacks of post insulators with parallel arms of unequal height, substation apparatus with insulating guys).

Table 5 – Factor K_k for multiple-unit structures with electrically parallel arms without jumpers

Number of parallel arms	1	2	3-5
K_k	1.0	1.05	1.10

The factor K_k for structures with more than five parallel arms, for complex multiple-unit structures with parallel and series-parallel arms (such as Y strings with double arms), for complex multiple-unit structures with metal jumpers, for structures made up by units of various configurations and generally for complex three-dimensional structures should be taken equal to 1.10.

The correction factor K_p is introduced for polymer insulators and takes into account their less contamination compared to glass and porcelain insulators, which should be determined depending on the PL in Table 6.

Table 6 – Dependence of K_p on PL [16]

PL	1	2	3	4
K_p	0.95	0.90	0.85	0.80

The correction factor K_h takes into account the work of supporting insulator strings and supporting insulators at altitude higher than 1000 meters above sea level, which should be determined depending on the altitude above sea level (Table 7).

Table 7 – Dependence of K_h on the altitude above sea level [4]

The altitude above sea level, m	From 1000 to 2000	From 2000 to 3000	From 3000 to 4000
K_h	1.05	1.10	1.15

4. Evaluation of the expected or predetermined specific number of electrical equipment outages caused by flashovers of polluted insulation, is performed with use of mathematical statistics methods [7,12,16,17].

3. CRITERIA FOR DETERMINING OF POLLUTION LEVELS AT THE SITE OF ELECTRICAL INSTALLATIONS

The following criteria are used to determine PL:

- characteristics of pollution sources;
- operating experience of outdoor insulation of overhead lines and switchgears;
- discharge voltage of insulators polluted under natural conditions;
- specific surface conductivity of insulators polluted under natural conditions;
- specific equivalent (by NaCl) surface density of contamination of insulators polluted under natural conditions;
- specific volume conductivity of a solution of pollutants that have fallen from the surface layer of the atmosphere to the surface of insulators or to collections of pollution [18].

When plotting of pollution level map, the criteria listed above can be used both individually and in various combinations. As a rule, for areas with natural pollution, regional pollution level maps (RPLM) are compiled, and for areas with industrial pollution local pollution level maps (LPLM) are compiled. Figure 1 shows the block diagram of the pollution levels mapping process.

Methods for determination of parameters used in pollution levels mapping process are shown in Figure 1, detailed information about the methods presented in [3,5,6,7,9,11,14,18]. In this paper only one method is presented [18] – the selection of insulation levels using the pollution collections.

Compared with IEC specifications [18], Russian standards provide more information: accounting for discharge voltage and specific surface conductivity of insulators with natural pollution, taking into account the characteristics of pollution sources, accounting for operating experience of electrical installations, and the possibility of using a statistical method for selection of outdoor insulation and zoning of the territory on the basis of pollution levels using maps.

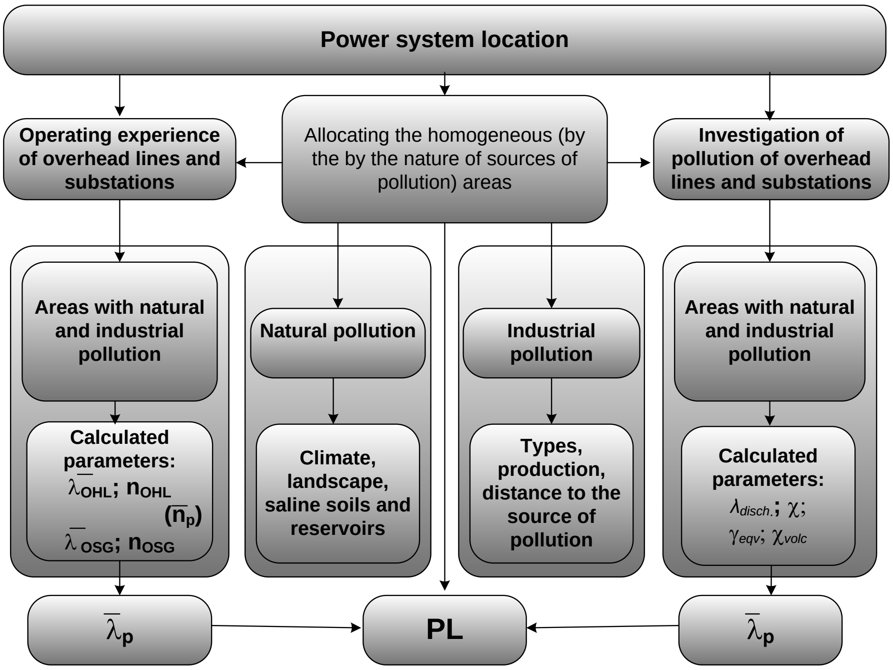

Figure 1 - Block diagram of the pollution levels mapping process

4. ALLOCATION OF AREAS WITH SIMILAR OPERATION CONDITIONS OF INSULATION

When allocating the homogeneous (by the presence of sources of pollution) areas, the main task is to correctly identify the characteristics that characterize the homogeneity of the territory, as well as the borders of the territory with these characteristics.

For this purpose, a map should be prepared for the area under consideration, on which the following object should be marked:

- route of overhead lines and substations areas;
- climatic regions, landscape-climatic regions;
- zones with different types of pollution;
- zones with different types of environment;
- sources of industrial emissions of pollutants into the atmosphere with their boundaries;
- coastline of saline water bodies;
- zones with cultivated and saline soils, with dry and wet dust storms, with non-native dust deposition, birds sitting on the traverse of overhead lines.

Allocation of homogeneous areas (zones) depending on the type of source of pollution is performed taking into account the criteria contained in Table 8.

Table 8 – Criteria for allocation of homogeneous areas

Sources of pollution	Criterion for determining PL and type of pollution
Type of pollution	Type A: solid contamination with soluble and insoluble components deposited on the surface of the insulator Type B: liquid contamination (electrolytes)
Type of environment	Coastal, desert, industrial, agricultural, forest, steppe, internal (low pollution without any clearly identified sources of pollution)
Industrial enterprises and production	Type of production, the estimated volume of production (thousand tons/year), distance from sources of pollution (m)
Thermal power plants and industrial boilers	Type and ash content (%) of fuel, power (MW), height of chimneys (m), distance from sources of pollution and moistening (m)
Cooling towers and spray pools	Circulating water conductivity (µS / cm), distance from sources of humidity (m)
Dumps of dusting materials, storage and sewage treatment buildings and structures, roads with intensive use of chemical anti-icing means	Distance from pollution sources (m)
Saline soils	Characteristics of the upper soil layer (the content of water-soluble salts, the level of deflation), the distance to the saline massif (m)
Saline water bodies (seas, lakes)	Estimated salinity of water (g/l), distance from humidification sources (m), area of lakes (km2)

5. DETERMINATION OF PL BY CHARACTERISTICS OF POLLUTION SOURCES

In areas with industrial pollution, only the type and factory load, as well as the distance to the source of industrial pollution, accompanied by atmospheric emissions of pollutants with potential hazards for insulation performance (with electrical conductivity in a humidified state) (Table 9) are taken into account.

Table 9 - General scheme for determining PL near industrial pollution sources

Estimated manufacturing output (chemistry, metallurgy, etc), thousand tons/year	PL at a distance from the pollution source, m							
	0-500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000-5000	>5000
up to 10	1	1	1	1	1	1	1	1
>10 to 500	2	1	1	1	1	1	1	1
>500 to1500	3	2	1	1	1	1	1	1
>1500 to 2500	3	3	2	1	1	1	1	1
>2500 to 3500	4	3	3	2	2	1	1	1
>3500 to 5000	4	4	3	3	3	2	2	1

The PL index and the distance from the pollution source differ significantly depending on the specific type, volume of output and distance from the pollution source.

Table 10 shows the PL depending on the salinity of the water and the distance from the water's edge for coastal areas with marine pollution (drift of saline water splashes).

Table 10 – Pollution levels in coastal areas of seas and lakes over 10.000 m^2[4]

Water basin	Design salinity of water. g/l	Distance from coast line. km	PL
Non-saline	up to 2	up to 0.1	1
Low salinity	over 2 up to 10	up to 0.1	2
		over 0.1 up to 1.0	1
Medium salinity	over 10 up to 20	up to 0.1	3
		over 0.1 up to 1.0	2
		over 1.0 up to 5.0	1
High salinity	over 20 up to 40	up to 1.0	3
		over 1.0 up to 5.0	2
		over 5.0 up to 10.0	1

The following climatic regions and territories are areas with 1st PL: tundra, forest-tundra, forest zone, vast swamps, meadows, forest-steppe and steppe in the absence of wind erosion and saline soils, agricultural areas in which chemical treatment of crops is not used, alpine areas, populated and built up area.

For the selection of areas with the 2nd PL and above the preparation of PLM is requires.

6. DETERMINATION OF POLLUTION LEVEL BY OPERATIONAL EXPERIENCE

For the areas with homogeneous pollution characteristics, where overhead lines and outdoor switchgear are located, a generalization and analysis of electrical installations insulation operating experience for a long-term period is made (preferably over 5 years and longer).

The analysis of accidents and failures causing automatic shutdowns on overhead lines and outdoor switchgears is aimed at establishing the relationship between the characteristics of pollution sources, insulation levels (specific creepage distance λ_p) and quantitative assessment of the reliability index (n_p), i.e. specific number of outages per year per 100 km of one overhead line or several overhead lines located in homogeneous areas (in terms of sources of pollution) caused by pollution of the insulation.

For each area identified by the presence of potential pollution sources (area, zone, region), using data on insulation characteristics and operating experience of overhead lines and outdoor switchgears, the values λ_{OHL} and n_p are calculated.

Depending on the index n_p the sufficiency or necessity of increasing the insulation level is established, i.e. the specific creepage distance (λ_{OHL}) for the considered homogeneous (according to the characteristics of pollution sources) territory.

The value of n_p is selected taking into account the requirements for reliability indexes.

Table 11 shows the permissible specific numbers of 110-750 kV overhead lines failures ($n_{p\ per}$) caused by contamination of the insulation.

Table 11 - Permissible specific number of OHL outages caused by contamination of insulator strings

OHL nominal voltage, kV	110	220	330	500	750
$n_{p\ per}$, outage/100 km per circuit·year	0.55	0.30	0.25	0.20	0.15

In cases where the value of n_p (operational) is bigger than $n_{p\ per}$, the average specific creepage distance λ_{OHL} is increased by multiplying by the reliability factor K_α (Table 12)

$$\lambda_p = \lambda_{OHL} \cdot K_\alpha, \tag{3}$$

Table 12 – K_α depending on n_p (operational)

n_p, outage/100 km per circuit·year (operational)	0.1	0.5	1.0	2.0	5.0
K_α	1	1.1	1.15	1.20	1.25

The calculated PL, taken for a homogeneous area, is determined according to Table 13, with use of calculated value of the specific creepage distance, determined by formula 3.

Table 13 – Selection of PL according to operating experience

λ_p, cm / kV	up to 2.8	>2.8 to 3.5	>3.5 to 4.4	>4.4 to 5.5	>5.5
PL	1	2	3	4	>4

7. DETERMINATION OF POLLUTION LEVELS ACCORDING TO THE CHARACTERISTICS OF INSULATORS POLLUTED IN NATURAL CONDITIONS

To select insulation levels, it is necessary to dismantle several insulators with a steady natural layer of contamination at the predetermined points of the study area. The characteristics of contaminated insulators, including the layer of pollution and atmospheric precipitation should be determined. To study the insulators polluted under natural conditions, it is possible to use cap and pin insulators of porcelain or glass, which have the same geometric dimensions and configuration of the insulating part.

Based on test results and measurements performed for selected homogeneous areas, the following estimated averaged parameters should be obtained, which are used to determine the required value of λ_p and PL:

λ_{disch} - the calculated value of the discharge specific creepage distance, cm/kV, characteristic of the studied area; specific surface conductivity of the pollution layer χ; equivalent surface density of natural salt contamination (on the content of NaCl) γ_{eqv}; specific volume conductivity of precipitation χ_{vol}; specific volume conductivity of an aqueous solution of a pollutant collected in a collection (C), χ_{volc}.

Laboratory tests of wetted insulators with a natural pollution layer and the collection of precipitation under natural conditions are carried out in accordance with the methods described in [3]. For example, insulators are moistened with water mist or steam to a state of saturation of the pollution layer.

The discharge specific creepage distance is determined by the equation:

$$\lambda_{disch}=L/U_{disch}, \tag{4}$$

where L is the length of the creepage distance (cm) of the tested insulator (insulator strings); U_{disch} is the average discharge voltage of an insulator (a string of insulators) with a natural layer of contamination, kV.

If conductive precipitation detected in a selected homogeneous area ($\chi_{vol} > 0.5$ μS/cm), the calculated value of λ_{disch} is determined taking into account the precipitation conductivity coefficient K_{con} (Table 14) depending on the specific volume conductivity of atmospheric precipitation χ_{vol}.

Table 14 – The dependence of the correction factor K_{con} on the conductivity of precipitation for methods for determining of PL with use of λ_{disch}, χ and γ_{eqv}

Specific volume conductivity of precipitation χ_{vol}, μS/cm	Correction factor K_{con}
above 0.5 through 1.0	1.1
above 1.0 through 2.0	1.15
above 2.0 through 5.0	1.25
above 5.0 through 10.0	1.35

With $\chi_{vol} > 0.5$ μS/cm, the value of λ, previously determined with use of λ_{disch}, χ and γ_{eqv}, should be increased by multiplying by the correction factor K_{con}.

Determination of PL by discharge voltage of insulators.

The ratio between the specific creepage distance λ_p and the parameter λ_{disch} is given:

$$\lambda_p = K_{mar} \cdot \lambda_{disch}, \tag{5}$$

where K_{mar} is the safety factor characterizing the increase in the discharge voltage of a single string (column) as compared to the voltage (relative to the ground) of the overhead line (switchgear) multiple string (column) unit. The values K_{mar} calculated with use of the field measurements of U_{disch} and χ of insulators with natural pollution and the statistical method [7], are given in Table 15.

Table 15 –Safety factor K_{mar} depending on PL according to field studies [7]

PL	1	2	3	4
K_{mar}	2.35	2.25	2.15	2.1

Estimation of the expected number of insulation flashovers n_p with ξ humidification (according to weather stations) can be performed as follows:

$$n_p \approx m\xi F\left(\frac{1-K_{mar}}{c_s K_{mar}}\right) = m\xi F(-x), \tag{6}$$

where n_p is the specific number of insulation flashovers during one year; m is the number of strings per 100 km overhead line; ξ is the number of dangerous for linear insulation humidifications per 1 year; c_s is the scattering coefficient, which characterizes the spread of discharge voltages of insulators contaminated in a homogeneous area; F is the integral function of the normal distribution; x is the argument of the normal distribution function

$$x = \left(\frac{1-K_{mar}}{c_s K_{mar}}\right). \tag{7}$$

The safety factor is determined by the formula:

$$K_{mar} = \frac{1}{1-x\cdot c_s}. \tag{8}$$

The calculated values λ_{disch}, determined by the formula (4), and accordingly, the PL taking into account the conductivity of precipitation (χ_{vol}) are given in table 16.

Table 16 – Determination of the required specific creepage distance λ_p and PL according to the measurement results of λ_{disch} [3]

λ_{disch}. cm/kV	χ_{vol}. μS/cm									
	<0.5		0.5÷1.0		1.0÷2.0		2.0÷5.0		5.0÷10.0	
	λ_p. cm/kV	PL	λ_p. cm/kV	PL	λ_p. cm/kV	PL	λ_p. cm/kV	PL	λ_p. cm/kV	PL
>1.2 to 1.5	2.8	1	3.1	2	3.3	2	3.5	3	3.8	3
>1.5 to 2.1	3.5	2	3.8	3	4.0	3	4.3	4	4.7	4
>2.1 to 2.3	4.4	3	4.7	4	5.0	4	5.4	5	5.7	5
>2.3 to 2.7	5.5	4	5.9	5	6.0	5	6.6	> 5	9.1	> 5
>2.7 to 3.3	6.4	5	6.9	> 5	7.3	> 5	7.8	> 5	8.3	> 5

In various climatic regions (Cuba, Egypt, Kazakhstan, and also on the territory of Russia), dependencies of U_{disch} on χ and γ_{eqv} were obtained, which were used in determining the dependence of λ_p on χ and γ_{eqv}.

The determining PL by the specific surface conductivity of the pollution layer is given in Table 17.

Table 17 – Determination of the required specific creepage distance λ_p and PL according to the measurement results [3,11]

χ. µS	χ_{vol}. µS/cm									
	<0.5		0.5÷1.0		1.0÷2.0		2.0÷5.0		5.0÷10.0	
	λ_p. cm/kV	PL	λ_p. cm/kV	PL	λ_p. cm/kV	PL	λ_p. cm/kV	PL	λ_p. cm/kV	PL
>1 to 3	2.8	1	3.1	2	3.3	2	3.5	3	3.8	3
>3 to 10	3.5	2	3.8	3	4.0	3	4.3	4	4.7	4
>10 to 15	4.4	3	4.7	4	5.0	4	5.4	5	5.7	5
>15 to 20	5.5	4	5.9	5	6.0	5	6.6	> 5	9.1	> 5
>20 to 30	6.4	5	6.9	> 5	7.3	> 5	7.8	> 5	8.3	> 5

The determination of PL with use of the equivalent density of salt contamination γ_{eqv} is given in Table 18. This criterion is not fundamentally different from that according to IEC method [18].

Table 18 – Determination of the required specific creepage distance λ_p and PL with use of the equivalent density of salt contamination γ_{eqv}

γ_{eqv}. mg/см^2	χ_{vol}. µS/cm									
	<0.5		0.5÷1.0		1.0÷2.0		2.0÷5.0		5.0÷10.0	
	λ_p. cm/kV	PL	λ_p. cm/kV	PL	λ_p. cm/kV	PL	λ_p. cm/kV	PL	λ_p. cm/kV	PL
> 0.01 - 0.03	2.8	1	3.1	2	3.3	2	3.5	3	3.8	3
> 0.03 - 0.06	3.5	2	3.8	3	4.0	3	4.3	4	4.7	4
> 0.06 - 0.15	4.4	3	4.7	4	5.0	4	5.4	5	5.7	5
> 0.15 - 0.3	5.5	4	5.9	5	6.0	5	6.6	> 5	9.1	> 5
> 0.3 - 0.5	6.4	5	6.9	> 5	7.3	> 5	7.8	> 5	8.3	> 5

Determination of PL by the volumetric conductivity of atmospheric pollution measured using collections (according to the method [18])

The relationship between PL and the specific volume conductivity of the aqueous solution of the pollutant χ_{volc} collected in the collection is given in Table 19.

Table 19 - Dependence of PL on the specific volume conductivity χ_{volc}

χ_{volc} (µS/cm)		PL
Monthly average χ_{volc} over one year	Monthly maximum χ_{volc} over one year	
<25	< 50	1
25 ÷ 75	50 ÷ 175	2
76 ÷ 200	176 ÷ 500	3
201 ÷ 350	501 ÷ 850	4
>350	>850	>4

In case of a non-coincidence of t PL determined with use of monthly average measurements of χ_{volc} over the year and monthly minimum, must select the highest value.

8. TECHNOLOGICAL FEATURES OF ELECTRONIC MAPS

Electronic maps are a set of data necessary for determining geographic, physical, climatic and other types of terrain, region, and area characteristics.

Geographical data determines the parameters of the coordinate system, the position of the object, the size of the terrain. These data are usually represented by three geometric forms, such as:

point (label), polyline (path, path) and geometric body (figure). Any geometric shapes are interrelated and contain the coordinates of certain points and the connections between them.

In addition to the geometric characteristics for each object, any amount of additional information can be stored. For example, information about the owner of the OHL or just the name of an object.

Before making out electronic maps, it is necessary to determine form and type of information it should contain. Various information on the electronic map can be stored in the database, in this case it is necessary to agree on the exact field names, dimensions and other necessary parameters in order to eliminate inconsistencies in the future and provide the ability to edit and replenish the PLM.

Electronic cards can be transferred and stored in various formats. As a base used formats that are supported by most software products for working with geographic data. The main criterion for the selection of the data format is the ability to store all the data that are consistent with the source data (database of the energy company), sufficient accuracy, compatibility with the GIS of energy company, and ease of use.

Software products capable of performing geometric transformations and calculations necessary for processing the initial geographical data of the map are used to compile electronic maps.

Electronic maps of contaminated areas are a collection of areas (zones) with a normalized estimated degree of contamination. Additional information of such areas (zones) can be the name of the area, type of pollution, level of pollution, recommendations on insulation levels, etc.

When compiling electronic pollution level maps, the source data are sites of pollution sources, state and cadastral boundaries, and wind roses in the area.

The pollution zone width, pollution level index are calculated for each pollution source. According to the inventory data or according to the data provided by the plant (source of pollution), the coordinates of the source site are located. Based on these data, a digital model of the territory occupied by the pollution source in a given coordinate system is created.

Using software products that allows to work with geometric forms, to convert them into the necessary formats for GIS system of an energy enterprise, a zone of pollution is built.

With the help of a wind rose, characteristic for a given area, the widths of pollution zones, their levels and quantity, and also taking into account the coordinates of the site of the pollution source (site corners), specially constructed diagrams are plotted describing the distribution of winds and zones with varying degrees of pollution.

Next, the zones of each pollution level of this source are constructed by circling the extreme points of the pollution diagrams at the corners of the source site. The resulting curve needs to be smoothed. The radius of rounding are selected based on the density of wind flows in a particular direction, the shape of the source area and other criteria that affect the shape of the final curve.

Each zone of each site is assigned a label indicating the pollution level, the coordinates (address and name) of the pollution source, region, region, city, etc.

The resulting data is converted into a data format for working with GIS systems and processed in an application for working with geographic data. With the help of these products, groups of data on the sources of pollution and zones of pollution levels are created.

Additionally, insulation parameters normalized for each specific pollution level can be entered. The required insulation level is calculated based on the characteristics of pollution sources, operating experience of overhead lines and switchgears, i.e. according to the method of compiling the conventional PLM.

The result is a digital representation of the pollution level zones for all the pollution sources under consideration with all associated data. Zones correspond to areas and are stored in the appropriate format.

The storage format allows both to modify existing areas and add new ones due to changed conditions or remarks that have arisen.

By default, data is stored in the geodetic coordinate system (latitude-longitude) WGS84.

The electronic map gives reliable values of PL in the area along the overhead lines routes and the switchgear sites, the geodetic coordinates of the OHL towers, the boundaries of the zones with different PL, the terrain plan along the OHL route, which in turn provide the necessary information to the operating organization along the OHL routes over its entire life cycle.

Digital maps serve as a basis on which the results of periodic inspections and measurements, the performance of certain types of work to maintain the reliable operation of the high-voltage lines and open switchgear in conditions of pollution and wetting can be superimposed.

Figures 2 and 3 show the digital maps (regional and local). These cards are used in the appropriate software.

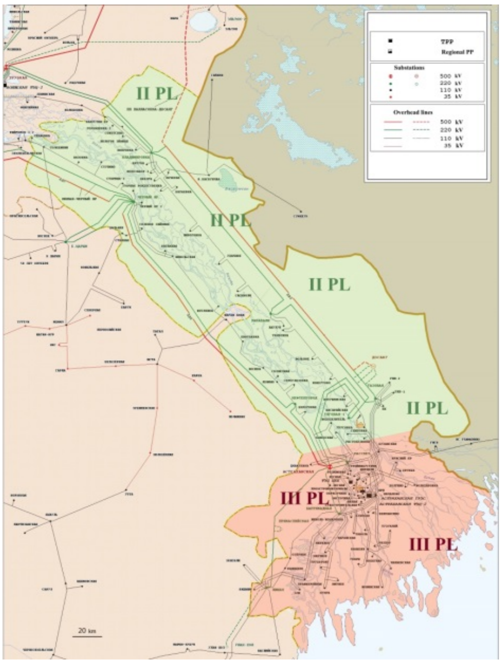

Figure 2 - Example of a regional pollution level map

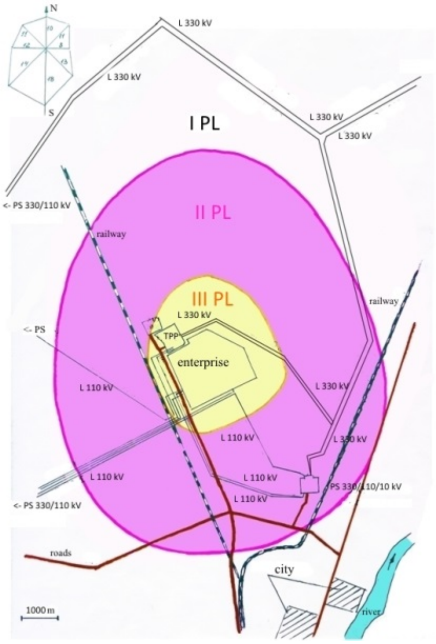

Figure 3 - Example of a local pollution level map

9. FEATURES OF SELECTION OF AUTDOOR INSULATION FOR ELECTRICAL INSTALLATIONS, WORKING UNDER DC VOLTAGE

The selection of outdoor insulation for direct current transmissions is made according to PLM, designed for AC electrical installations, taking into account the specifics of the insulation operation at DC voltage [15].

The L for outdoor insulation operating at DC voltage is determined by the formula:

$$L= \lambda \cdot U_{dc} \cdot K_L \cdot K_{dc} \cdot K_t \cdot K_n, \qquad (9)$$

where $U_{dc}\cdot$ is the peak pole-to-earth voltage, kV;

λ - determined depending on PL, previously determined for AC electrical installations (cm / kV) (see paragraphs 5, 6, 7);

K_L - correction factor, taking into account the effectiveness of the use of the creepage distance at DC voltage;

K_{dc} - correction factor, taking into account the difference between the discharge voltage of the insulators at DC and AC voltage with the same pollution level;

K_t - correction factor, taking into account the different contamination of insulators at DC and AC voltage;

K_n - correction factor, which takes into account the nonlinearity of the discharge voltage of polluted and wetted insulators and the insulator strings depending on their length.

Table 20 shows the initial data for estimating the correction factor for the selection of outdoor insulation for DC transmissions

Table 20 - Evaluation of the correction factors K_L, K_{dc}, K_t , K_n

<table>
<tr><th>Correction factor</th><th>Type of insulator</th><th colspan="5">Determination of the coefficients</th></tr>
<tr><td rowspan="6">K_L</td><td rowspan="2">Cap-and-pin (glass, porcelain)</td><td colspan="5">1 for L/D<1.1</td></tr>
<tr><td colspan="5">K_L = 1+0.6(L/D-1.1) for L/D from 1.1 for 1.6</td></tr>
<tr><td rowspan="2">Long- rod (porcelain)</td><td colspan="5">1 for L/h<2.5</td></tr>
<tr><td colspan="5">K_L = 1+0.2(L/h–2.5) for L/h from 2.5 for 4</td></tr>
<tr><td rowspan="2">Long- rod (composite)</td><td colspan="5">1 for L/h<3</td></tr>
<tr><td colspan="5">K_L = 1+0.15(L/h–3) for L/h from 3 for 4</td></tr>
<tr><td rowspan="2">K_{dc}</td><td rowspan="2">Cap-and-pin (glass, porcelain)</td><td>PL</td><td>1</td><td>2</td><td>3</td><td>4</td></tr>
<tr><td>K_{dc}</td><td>1,05</td><td>1,10</td><td>1,20</td><td>1,25</td></tr>
<tr><td rowspan="3">K_t</td><td>Cap-and-pin (glass, porcelain)</td><td colspan="5">1.0 in the areas of 1-st PL
1.0–1.4 in the areas of 2nd - 4th PL</td></tr>
<tr><td>Long- rod (porcelain)</td><td colspan="5">1.0–1.4 in the areas of 2nd - 4th PL</td></tr>
<tr><td>Long- rod (composite)</td><td colspan="5">Additional information is required</td></tr>
<tr><td rowspan="2">K_n</td><td rowspan="2">Cap-and-pin (glass, porcelain)</td><td colspan="5">1 for χ>5 µS</td></tr>
<tr><td colspan="5">$K_n = 0.865 + 0.0054n$
(n – number of units in the string more than 25 for $\chi \le 5$ µS)</td></tr>
<tr><td colspan="7">Where
L - the insulator creepage distance
D - insulator diameter
h - insulating height of the insulator</td></tr>
</table>

Indexes in formula 9 and table 20 relate only to the selection of DC insulation.

Longer burning of partial arcs at a DC voltage (compared to AC voltage) leads to the blowing of the arc from the surface of the insulator. With this mechanism of development of arcs, partial shunting of sections (along the length of the leakage path) of an insulator with closely spaced ribs occurs. Therefore, the creepage distance at DC voltage can be used in a smaller extent than at AC voltage. The insulators with overhang of large and small diameter ribs, with two small diameter ribs between the large diameter ribs will be most effective in areas with strong pollution.

When selecting insulators under contaminated conditions at DC voltage, the polarity of the applied voltage does not have any significant effect, since the overlap of the insulator is primarily determined by the energy processes on its surface (heating of the pollution layer, its drying, the formation of partial arcs on the dried parts of the insulator). In Russia it is customary to test contaminated insulators with negative polarity.

CONCLUSIONS

The paper summarizes the main criteria and approaches of the present-day Russian pollution level mapping (PLM) system for selection of external insulation of DC and AC electric installations operating in contaminated and humidified conditions at operating voltage. Over the past 30 years PLMs were made for many countries with different climatic conditions: Russia, Cuba, Egypt, Mongolia, Estonia, Kazakhstan, Turkmenistan.

PLM is a special geographic map, containing marked industrial and natural sources of pollution, electric equipment (overhead lines (OHL) and substations), contours, showing areas with identical pollution levels, taking into account the impact of atmospheric boundary layer pollution on reducing the dielectric strength of electrical equipment (OHL and outdoor switchgear) insulation.

Approaches and methods for selection of externa insulation, described in this paper, can be used when selecting insulation of high-voltage electrical installations in both regions and local zones. The proposed methods and criteria can be used in the development or revision of normative documents.

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