Pollution mapping methodology for selection of external insulation of HV AC and HV DC electric transmission

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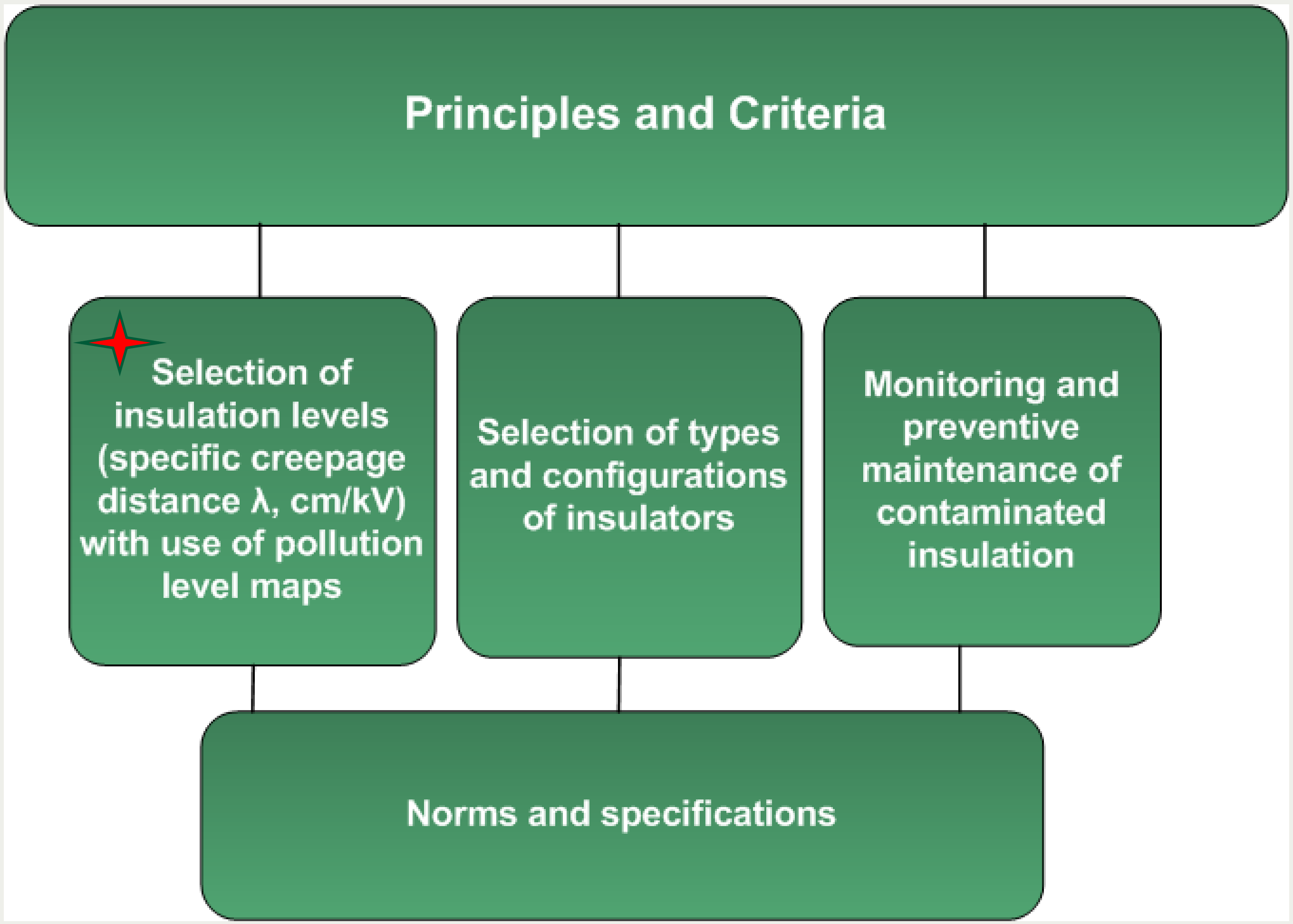
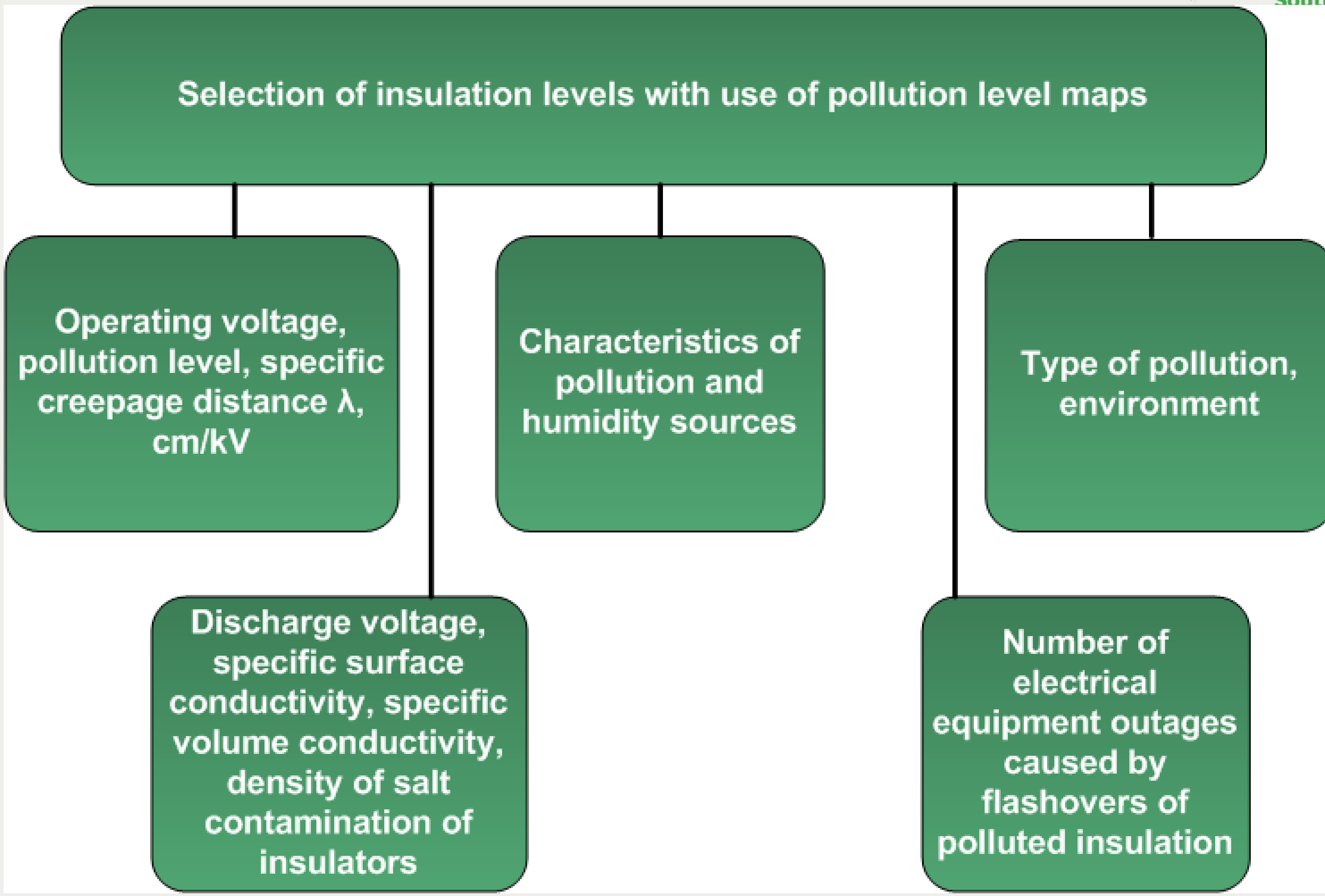
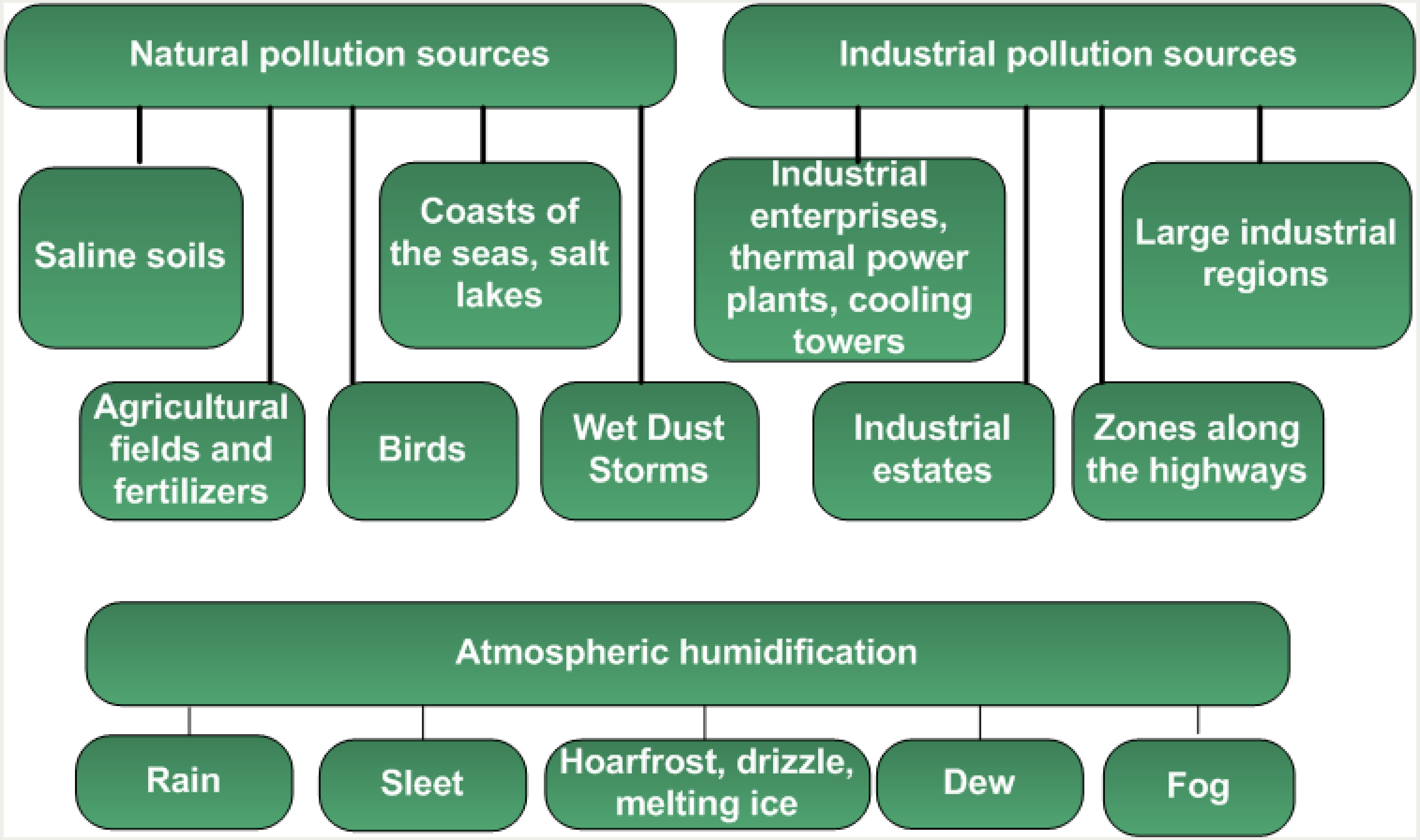
Selection of outdoor insulation of HV electric equipment




Selection of insulation levels with use of pollution level maps
Operating voltage, pollution level, specific creepage distance λ, cm/kV
Characteristics of pollution and humidity sources
Type of pollution, environment
Discharge voltage, specific surface conductivity, specific volume conductivity, density of salt contamination of insulators
Number of electrical equipment outages caused by flashovers of polluted insulation

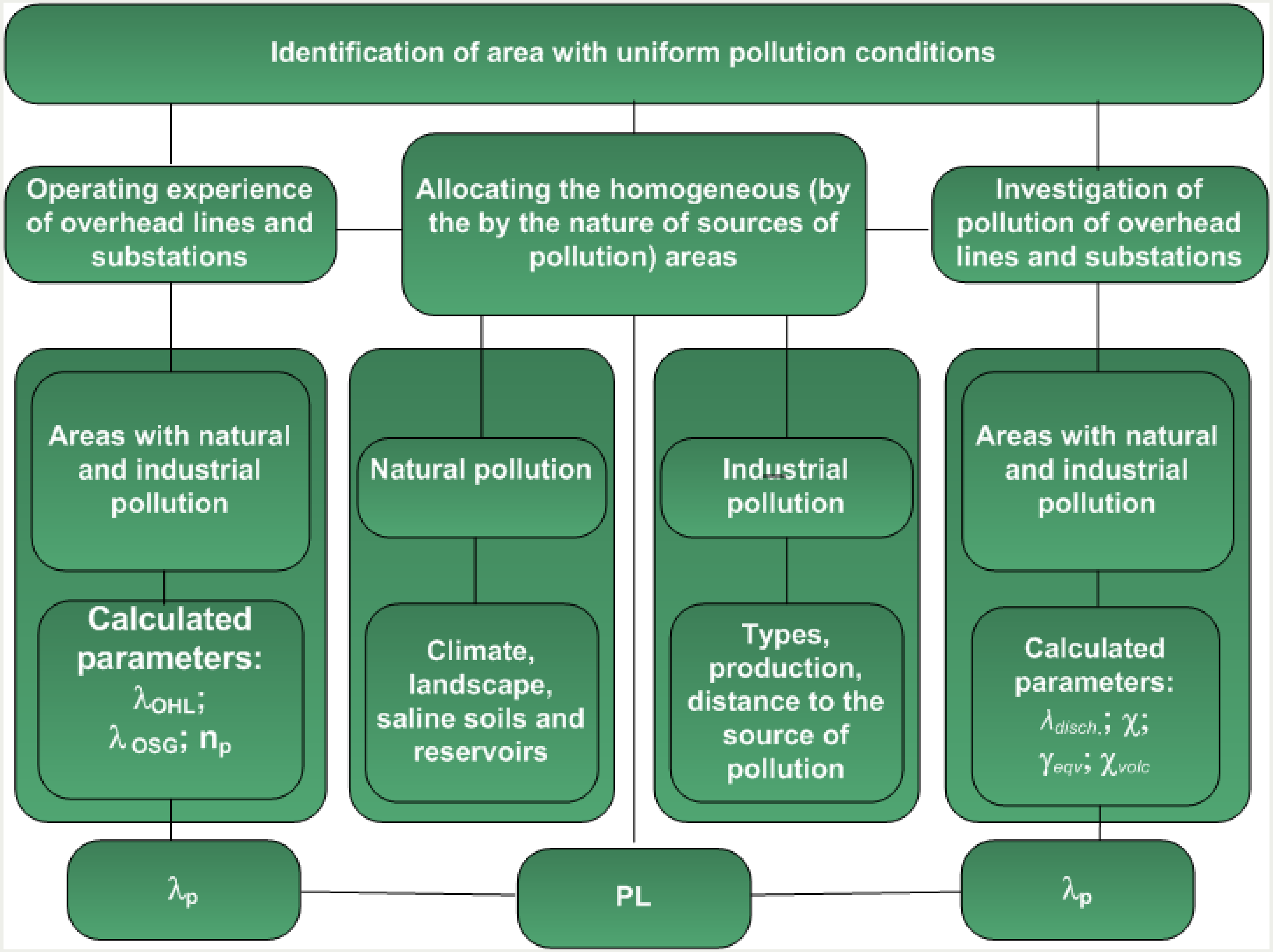
Pollution and humidity sources



Specific creepage **distance λ of** outdoor insulation

PL	λ, cm/kV (not less than), at nominal voltage, kV	
	up to 35	110÷750
1	3.3	2.8
2	4.1	3.5
3	5.3	4.4
4	7.2	5.5

Block diagram of the pollution levels mapping process



Criteria for Identification of areas with uniform pollution conditions

Sources of pollution	Criteria
Industrial enterprises and production	Type of production, the estimated volume of production (thousand tons/year), distance from sources of pollution (m)
Saline water bodies (seas, lakes)	Estimated salinity of water (g/l), distance from humidification sources (m)
Natural rainfall with high electrical conductivity	Rainfall conductivity (µS / cm)
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	Characteristics of materials and reagents, 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)

Identification of areas with uniform pollution conditions 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

Identification of areas with uniform pollution conditions near coastal areas of seas and lakes over 10.000 m^2

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

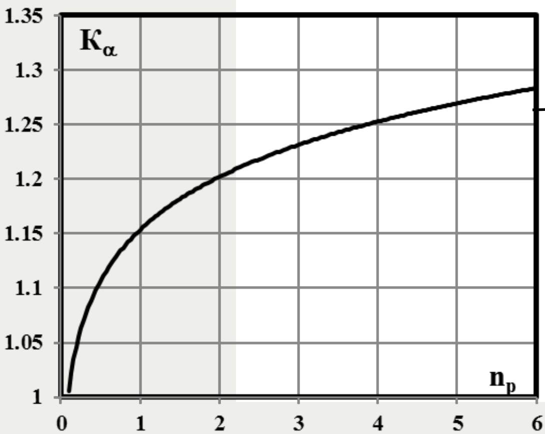
Determination of PL by operational experience of outdoor insulation in the pre-selected areas with uniform pollution conditions

Determination of λ_p,cm/kV

Determination of n_p, outage/100 km year

Adjustment p for np
$\lambda = \lambda_p \times K\alpha$

Determination of PL according to operating experience (adjusted λ_p)



Allowable number of electrical equipment outages caused by flashovers of polluted insulation

kV	n_p
110	0.55
220	0.30
330	0.25
500	0.20
750	0.15

λ, cm / kV	up to 2.8	2.8 - 3.5	3.5 - 4.4	4.4 - 5.5	above 5.5
PL	1	2	3	4	above 4

Determination of PL according to the characteristics of insulators polluted in natural conditions

- Discharge specific creepage distance

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

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

- Specific creepage distance λ_p

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

K_{mar} - 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.

Safety factor K_{mar} depending on PL according to field studies:

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

Determination of the required specific creepage distance λ_p and PL according to the measurement results of λ_{disch} taking into account the volume conductivity of atmospheric precipitation χ_{vol}

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 - 1.5	2.8	1	3.1	2	3.3	2	3.5	3	3.8	3
1.5 -2.1	3.5	2	3.8	3	4.0	3	4.3	4	4.7	4
2.1 - 2.3	4.4	3	4.7	4	5.0	4	5.4	5	5.7	5
2.3 - 2.7	5.5	4	5.9	5	6.0	5	6.6	> 5	7.1	> 5
2.7 - 3.3	6.4	5	6.9	> 5	7.3	> 5	7.8	> 5	8.3	> 5

- **Determination of PL use of the specific surface conductivity of the pollution layer taking into account the volume conductivity of atmospheric precipitation χ_{vol}**

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 - 3	2.8	1	3.1	2	3.3	2	3.5	3	3.8	3
3 - 10	3.5	2	3.8	3	4.0	3	4.3	4	4.7	4
10 - 15	4.4	3	4.7	4	5.0	4	5.4	5	5.7	5
15 - 20	5.5	4	5.9	5	6.0	5	6.6	> 5	7.1	> 5
20 - 30	6.4	5	6.9	> 5	7.3	> 5	7.8	> 5	8.3	> 5

- **Determination of PL with use of the equivalent density of salt contamination γ_{eqv} taking into account the volume conductivity of atmospheric precipitation χ_{vol}**

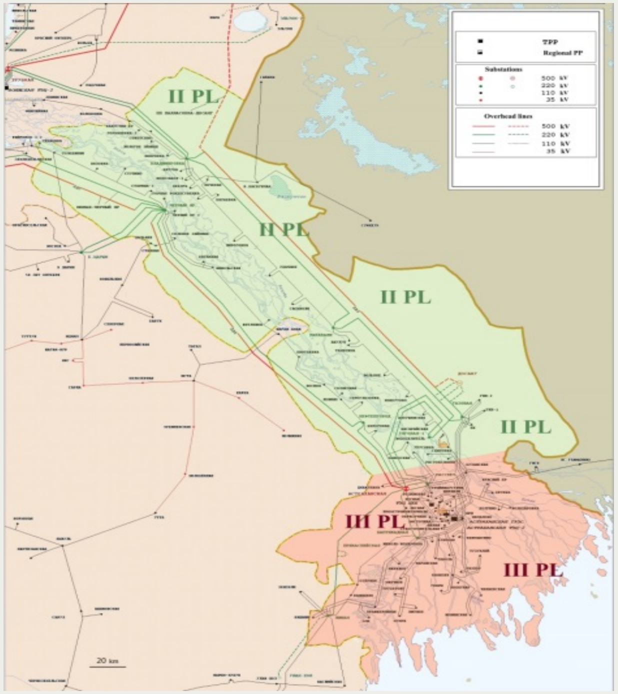
γ_{eqv}. mg/cм²	χ_{vol}, μS/cm									
	<0.5		0.5÷1.0		1.0÷2.0		2.0÷5.0		5.0÷10.0	
	λ_p. cm/kV	PL	λ_p. cm/kV	PL	λ_p. cm/kV	PL	λ_p. cm/kV	PL	λ_p. cm/kV	PL
0.01 - 0.03	2.8	1	3.1	2	3.3	2	3.5	3	3.8	3
0.03 - 0.06	3.5	2	3.8	3	4.0	3	4.3	4	4.7	4
0.06 - 0.15	4.4	3	4.7	4	5.0	4	5.4	5	5.7	5
0.15 - 0.3	5.5	4	5.9	5	6.0	5	6.6	> 5	7.1	> 5
0.3 - 0.5	6.4	5	6.9	> 5	7.3	> 5	7.8	> 5	8.3	> 5

Determination of PL with use of the volume conductivity χ_{volc} of atmospheric pollution measured using collections (according to IEC 60815)

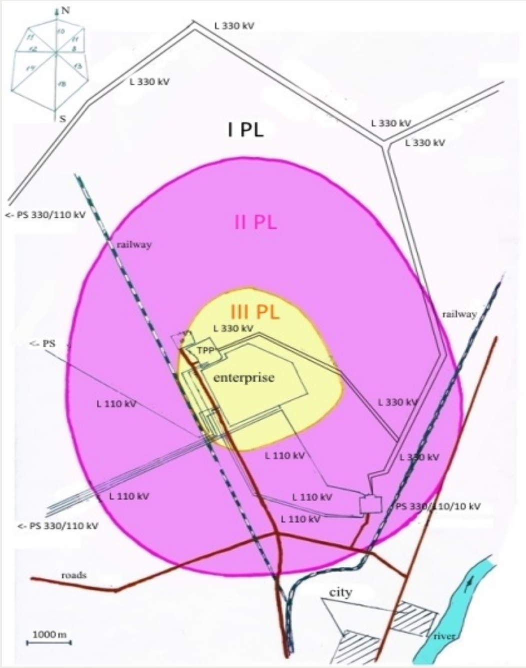
χ_{volc} (μS/cm)		PL
Monthly average χ_{volc} over one year	Monthly maximum χ_{volc} over one year	
<25	< 50	**1**
25 ÷ 75	50 ÷ 175	**2**
76 ÷ 200	176 ÷ 500	**3**
201 ÷ 350	501 ÷ 850	**4**
>350	**>850**	**>4**

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.

Pollution level maps



Example of a regional pollution level map



Example of a local pollution level map

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.
- 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 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 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.

Features of selection of outdoor insulation for electrical installations under DC voltage

- The L for outdoor insulation operating at DC voltage

$$L = \lambda \cdot U_{dc} \cdot K_L \cdot K_{dc} \cdot K_t \cdot K_n,$$

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

- λ - determined depending on PL, previously determined for AC electrical installations (cm / kV);
- 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.

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 $\chi \leq 5$ 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>

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