PARIS 2022

NIIPT

Study Committee B2

Overhead Lines

10364_2022

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

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Motivation

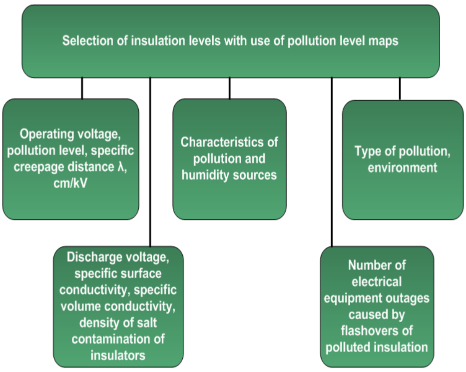
This study aims to develop methods for selection of insulation levels of DC and AC overhead lines using mathematical statistics methods when developing regional and local pollution level map for areas with natural and industrial pollution sources allowing choosing external insulation levels of DC and AC electric installations with required (specified) reliability (the number of flashovers), but without excess margins.

Method/Approach

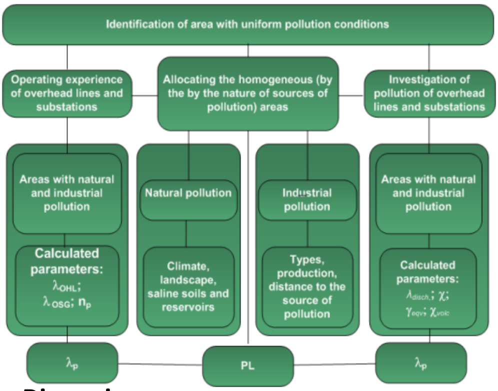
As a result of summarizing the operating experience of electrical installations, calculations and researches, analysis of bibliography on the subject under consideration, the following practical approaches have been accepted:

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. Determination of pollution level (PL) along the OH line route based on field tests, including mathematical statistics.
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)
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.

Objects of investigation



Experimental setup & test results



Discussion

Pollution level can be determined with use of pollution level maps.

The first step: allocating the homogeneous (by the nature of sources of pollution) areas.

In each homogeneous region the pollution level can be determined by six criteria both individually and in various combinations:

- 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 atmospheric pollutants fell out to pollution collector.

Conclusion

The paper summarizes the main criteria and approaches of the present-day Russian pollution level mapping (PLM) system for selection of outdoor 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.

Approaches and methods for selection of outdoor 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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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

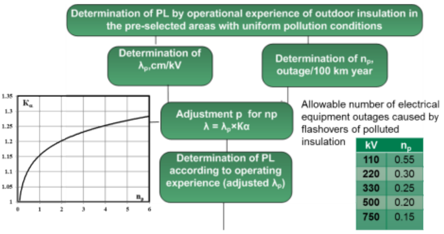
Identification of areas with uniform pollution conditions near industrial pollution sources

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

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 pollution level by operating experience



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 with 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/cm²	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

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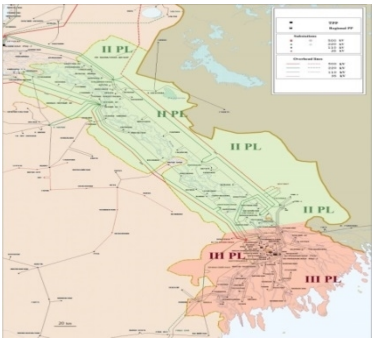
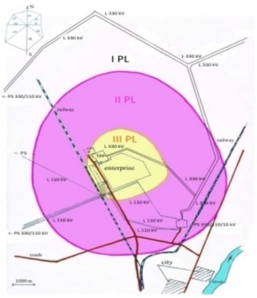
Pollution level maps



Example of a regional pollution level map



Example of a local pollution level map

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

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

Where
- L - the insulator creepage distance
- D - insulator diameter
- h - insulating height of the insulator