SECTION EIGHTEEN
GROUNDING AND OVERVOLTAGE PROTECTION OF OVERHEAD POWER LINES WITH VOLTAGES ABOVE 1000 V

277. Overhead power lines with voltages from 110 to 400 kV must be continuously protected by ground wires against direct lightning strikes. In overhead lines up to 35 kV, ground wires must be installed at the approaches of 35 kV lines to substations.

278. For 6–10 kV overhead lines with insulated conductors installed in built-up areas, running parallel to roads and pedestrian paths or crossing them, overvoltage protection devices must be installed every 250–300 meters. In main lines, these devices must be installed on both sides of the insulator, and in branches – only on the consumer side of the insulator.

279. When overhead lines are protected from direct lightning strikes by ground wires, the following requirements must be met:

- 279.1. For single-pole reinforced concrete and metal towers with one ground wire, the protection angle must not exceed 30°, and with two ground wires – not more than 20°.
- 279.2. For metal towers with horizontally arranged conductors and two ground wires, the protection angle relative to the outer conductors must not exceed 20°.
- 279.3. For reinforced concrete portal towers, the protection angle for outer conductors must not exceed 30°.
- 279.4. If the overhead line is protected by two ground wires, the distance between them must not exceed five times the vertical distance between the ground wire and the conductor.

280. The vertical distance between the ground wire and the conductors at the midpoint between towers, regardless of wind-induced sag, must meet the conditions specified in Table 3 of Annex 4 of the Rules and must not be less than the vertical distance between the ground wire and the conductor at the tower. For other span lengths, distances are determined by interpolation.

281. In all 220–400 kV overhead line towers, ground wires must be connected to insulators shunted with 40 mm spark gaps. If a lightning protection wire with an optical cable is used, it must be grounded at every tower.

In anchor spans up to 10 km long, ground wires must be grounded once, using special clamps at the anchor tower. If the spans are longer, the number of grounding points must be sufficient to ensure that, in the event of a short circuit, the maximum longitudinal electromotive force induced in the wire does not break through the spark gaps.

When attaching ground wires to towers, it is advisable to use glass insulators.

If the ground wire is suspended using multiple insulators (for de-icing or communication purposes), the spark gap size must be coordinated with the electrical resistance of the insulator string used to attach the wire to the tower.

For 330–400 kV overhead lines, the ground wire must be grounded at every tower within 2–3 km of the substation, unless it is used for other purposes.

In 110 kV and lower voltage overhead lines, the ground wire must be attached to insulators only at anchor metal or reinforced concrete towers, if the wire is not used for de-icing.

282. Cable sections of overhead lines must be protected from atmospheric overvoltage's by surge arresters installed at both ends of the cable. The grounding terminal of the arrester, the metallic sheath of the cable, and the cable end must be interconnected in such a way that the connecting wire is as short as possible. The grounding terminal of the surge arrester must be connected to the grounding device with a separate conductor.

283. At river, water body, and similar crossings of overhead lines, towers higher than 40 m that are not equipped with ground wires must be fitted with surge arresters (see Clause 313 of the Rules).

284. In overhead lines, the distances between live conductors and fittings, and grounded parts of towers, must be no less than those specified in Table 4 of Annex 4 of the Rules.

285. The distances between conductors at the tower in places of conductor transposition, layout changes, and branch connections must be no less than those specified in Table 5 of Annex 4 of the Rules.

286. At line crossings and approaches to other objects, additional requirements for overvoltage protection apply. The Rules for the Installation of Electrical Lines and Installations must also be followed.

287. Grounding is required in overhead lines for:

287.1. Towers of overhead lines with ground wires or other atmospheric overvoltage protection devices. The grounding resistance of towers must not exceed the values specified in Table 6 of Annex 4 of the Rules.

287.2. Reinforced concrete and metal towers of 6–35 kV overhead lines. In built-up areas, the grounding resistance of 6–10 kV overhead lines and all 35 kV overhead lines must not exceed the values specified in Table 6 of Annex 4 of the Rules. In non-urban areas where the soil resistivity is less than 100 Ω·m, the grounding resistance of towers must not exceed 30 Ω. In undeveloped areas, a steel conductor with a surface area of at least 500 cm^2 is used as a grounding electrode for 6–10 kV line towers.

287.3. Towers of overhead lines where measuring transformers, disconnectors, fuses, and other devices are installed. For 10 kV and higher voltage overhead lines, the grounding resistance of towers must not exceed the values specified in Table 6 of Annex 4 of the Rules.

287.4. Towers of 110–330 kV overhead lines without ground wires or other atmospheric overvoltage protection devices, if necessary for reliable operation of relay protection and automation equipment. The grounding resistance values of overhead line towers must be determined during project design.

288. The grounding resistance of lightning protection grounding devices for towers of overhead lines protected by ground wires is measured with the ground wire disconnected, and for other purposes – with the ground wire connected.

In sections of overhead lines protected by ground wires, the grounding resistance of towers higher than 40 m must be reduced by half compared to the values specified in Table 6 of Annex 4 of the Rules.

It is advisable to measure the grounding resistance of overhead lines in summer when the resistance is at its highest.

289. In clay, loam, sandy loam, and other soils with a specific resistivity of less than 500 Ω·m, it is advisable to use the reinforcement of reinforced concrete foundations and footings of high-voltage overhead line towers as grounding electrodes. If the grounding resistance is insufficient, an artificial grounding device must be installed. In soils with a specific resistivity greater than 500 Ω·m, an artificial grounding device must be installed to ensure the required grounding resistance. Reinforced concrete foundations must also be connected to the artificial grounding device, but their conductivity should not be considered in resistance calculations.

For 6–35 kV overhead line towers, only artificial grounding devices must be installed. Natural grounding devices may also be used, but their resistance should not be included in the calculations.

290. Reinforced concrete foundations of overhead line towers are used as natural grounding electrodes (except as specified in Clause 289 of the Rules), provided that a metallic connection is ensured between the mounting bolts and the foundation reinforcement. For towers at railway crossings, the reinforcement of foundations and footings must not be used as grounding electrodes.

The bituminous coating of reinforced concrete foundations and towers used as grounding devices does not need to be considered.

The resistance of reinforced concrete foundations, footings, and underground parts of towers must be measured no less than two months after installation.

291. For grounding of reinforced concrete towers, longitudinal bars of both prestressed and non-prestressed reinforcement, interconnected and connected to the grounding electrode, are used as grounding conductors. The reinforcement used for grounding must be thermally resistant and must not heat up more than +60 °C.

Guy wires of reinforced concrete towers must be used as additional grounding conductors. In this case, the free end of the guy wire must be connected to its working part using a special clamp.

Ground wires and insulator mounting hardware on crossarms of reinforced concrete towers must be connected to the grounding conductor or grounded reinforcement.

292. The cross-sectional area of the grounding conductor laid along the tower must be at least 35 mm^2, and the diameter of single-core grounding conductors must be at least 10 mm. Hot-dip galvanized, or aluminum-zinc coated steel wires with a diameter of no less than 6 mm must be used.

In metal and reinforced concrete towers of overhead lines, grounding conductors must be welded or bolted together.

293. Grounding electrodes for overhead lines must be installed at a depth of no less than 0.5 m, and in arable land – no less than 1 m.

ANNEX 4 OF THE GENERAL RULES FOR THE INSTALLATION OF ELECTRICAL EQUIPMENT

Table 3. Minimum Distances Between Ground Wire and Conductor at Mid-Span

Span Length (m)	Minimum Vertical Distance (m)	Span Length (m)	Minimum Vertical Distance (m)
100	2.0	700	11.5
150	3.2	800	13.0
200	4.0	900	14.5
300	5.5	1000	16.0
400	7.0	1200	18.0
500	8.5	1500	21.0
600	10.0		

Table 4. Minimum Distances Between Overhead Line Conductors and Grounded Parts

Design Condition	**Distances (cm) at Line Voltage**					
	up to 10 kV	up to 35 kV	up to 110 kV	up to 220 kV	up to 330 kV	up to 400 kV
Atmospheric Overvoltages	20 (15)	40	100	210	260	300
Internal Overvoltages	10	30	80	130	215	280
Operating Voltage	–	10	25	50	80	100

Table 5. Minimum Distances Between Phase Conductors of Overhead Lines on the Tower

Design Condition	**Distances (cm) at Line Voltage**					
	up to 10 kV	up to 35 kV	up to 110 kV	up to 220 kV	up to 330 kV	up to 400 kV
Atmospheric Overvoltages	20	50	135	280	310	400
Internal Overvoltages	22	44	100	265	280	420

Design Condition	Distances (cm) at Line Voltage					
	up to 10 kV	up to 35 kV	up to 110 kV	up to 220 kV	up to 330 kV	up to 400 kV
Operating Voltage	–	20	45	110	140	200

Table 6. Maximum Grounding Resistance of Overhead Line Towers

Soil Resistivity ρ, (Ω·m)	Maximum Grounding Resistance (Ω)
≤ 100	10
100 < ρ ≤ 500	15
500 < ρ ≤ 1000	20
1000 < ρ ≤ 5000	30
> 5000	$6 \times 10^{-3}\rho$