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TECHNICAL SPECIFICATION

colour inside

UHV AC transmission systems –
Part 202: UHV AC Transmission line design

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UHV AC TRANSMISSION SYSTEMS –

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FOREWORD

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IEC TS 63042-202 has been prepared by IEC technical committee 122: UHV AC transmission systems. It is a Technical Specification.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
122/113/DTS	122/116/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts in the IEC 63042 series, published under the general title *UHV AC transmission systems*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
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UHV AC TRANSMISSION SYSTEMS –

Part 202: UHV AC Transmission line design

1 Scope

This part of IEC 63042 provides common rules for the design of overhead transmission lines with the highest voltages of AC transmission systems exceeding 800 kV, so as to provide safety and proper functioning for the intended use.

This technical specification aims to give the main principles for the design of UHV AC overhead transmission lines, mainly including selection of clearance, insulation coordination and insulator strings design, bundle-conductor selection, earth wire/optical ground wires selection, tower and foundation design, environmental consideration. The design criteria apply to new construction, reconstruction and expansion of UHV AC overhead transmission line.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60826, *Design criteria of overhead transmission lines*

IEC 61284, *Overhead lines – Requirements and tests for fittings*

IEC 61854, *Overhead lines – Requirements and tests for spacers*

IEC 61897:2020, *Overhead lines – Requirements and tests for Stockbridge type aeolian vibration dampers*

IEC 60794-4-10, *Optical fiber cables – Part 4-10: Family specification – Optical ground wires (OPGW) along electrical power lines*

IEC TS 62993, *Guidance for determination of clearances, creepage distances and requirements for solid insulation for equipment with a rated voltage above 1 000 V AC and 1 500 V DC, and up to 2 000 V AC and 3 000 V DC*

IEC 62110, *Electric and magnetic field levels generated by AC power systems – Measurement procedures with regard to public exposure*

CISPR TR 18-1:2017, *Radio interference characteristics of overhead power lines and high-voltage equipment – Part 1: Description of phenomena*

CISPR TR 18-2:2017, *Radio interference characteristics of overhead power lines and high-voltage equipment – Part 2: Methods of measurement and procedure for determining limits*

CISPR TR 18-3:2017, *Radio interference characteristics of overhead power lines and high-voltage equipment – Part 3: Code of practice for minimizing the generation of radio noise*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
UHV AC
highest voltage of AC transmission system exceeding 800 kV

3.2
residential area
populated areas, such as industrial area, port, wharf, rail station and towns

4 Symbols and abbreviations

AC	alternating current
AAC	all-aluminium-conductor
AAAC	all-aluminium-alloy-conductor
ACAR	aluminium-conductor-alloy-reinforced
ACSR	aluminium-conductor-steel-reinforced
AACSR	aluminium-alloy-conductor-steel-reinforced
ACSS	aluminium-clad-steel-strand
AN	audible noise
BFR	back-flashover rate
CFO	critical flashover
EDS	everyday stress
EGM	electrical geometric model
EHV	extra high voltage
ESDD	equivalent salt deposit density
HV	high voltage
ICNIRP	international commission on non-ionizing radiation protection
LPM	leader progression model
MSC	mid span compression
NSDD	non soluble deposit density
OPGW	optical ground wires
RI	radio interference
ROW	right of way
RTV	room temperature vulcanizing
SFFOR	sum of shielding failure flashover rate
SPS	site pollution severity
SS	steel-strand
UHV	ultra high voltage

USCD	unified specific creepage distance
UTS	ultimate tensile strength

5 UHV AC transmission line requirements

5.1 General requirements

In designing of UHV AC overhead transmission lines, several significant factors should be considered, they are requirements of reliability, electrical characteristics, mechanical characteristics, security, safety, environment and economy.

5.2 Reliability requirements

– Reliability of UHV AC overhead transmission lines should be high as the transmission capacity is large and UHV AC lines form an important part of the transmission network.

– Load-strength and other design requirements as per IEC 60826.

5.3 Electrical requirements

– Selection of appropriate conductor bundle has a significant influence on the performance of UHV AC overhead transmission lines. It should meet the basic requirements of ampacity, control of voltage drops, corona loss, radio interference and audible noise. Besides, it can be determined by comprehensive comparison in terms of economy and technology.

– Ground wires should meet the requirements of lightning protection, fault current, induced voltage, clearance between conductor and earth wire.

– External insulation configuration should ensure safe operation of transmission line under power frequency voltage, switching overvoltage, lightning overvoltage, and pollution conditions.

– As for tower, the configuration should be decided based on the electrical considerations, insulation requirements, economy, reliability, ROW requirements and clearance to buildings and obstruction and maintenance, etc.

5.4 Security requirements

Security requirements correspond to special loads and/or measures intended to reduce probability of uncontrollable progressive (or cascading) failures.

5.5 Safety requirements

Personal injury and safety risk should be avoided during construction and operation.

5.6 Environmental impact

Based on requirements of various countries, the environmental impact of transmission lines, such as electric field, magnetic field, audible noise, radio interference, wind noise, etc., should be controlled.

5.7 Economy

The design of the UHV AC overhead transmission lines should be based on evaluation of capital cost, operation and maintenance costs, and losses so as to have a balance between performance and cost.

6 Selection of clearance

6.1 General

For the selection of various clearances, the calculated values should be verified through experimental results. General principles for selection of clearances for transmission lines are covered under present IEC standards, which are IEC 60950, IEC TS 62993. Specific Guidelines for selection of clearances for UHV AC transmission lines are covered under this document.

6.2 Air gap, tower clearances (strike distance)

6.2.1 Power frequency voltage

For UHV AC transmission lines, determination of minimum clearance under power frequency voltage considers continuous operating voltage rather than temporary overvoltage.

The air clearance under the power frequency voltage is generally considered assuming that the maximum wind speed occurs concurrently.

The power-frequency 50 % flashover voltage $U_{50\ \%}$ for the air clearance between conductor and support under continuous operating voltage can be calculated as referred in IEC 60071-1 and other international practices.

6.2.2 Switching overvoltage

In determining the insulation levels required by switching overvoltage occurring on UHV overhead transmission line, the statistical approach or simplified statistical approach can be used, regarding the overvoltage amplitude and insulation strength as random variables.

Switching overvoltage can be predicted based on the engineering conditions. The items needing to be predicted should include the amplitude probability distribution of overvoltage at various points, statistical overvoltage, coefficient of variation, and time-to-peak of overvoltage.

Given the unlikelihood that switching overvoltage and maximum wind speed appear concurrently, the wind speed concurrent with the switching overvoltage can be taken as a value smaller than maximum wind speed. Designers can reduce wind speed according to required reliability.

Swing angles having a probability of occurrence of 1 % or more during a year should be combined with the distance necessary to withstand switching or lightning surges.

The specific value of wind speed is to be determined by the respective countries at their own discretion.

The 50 % switching impulse flashover voltage of the air clearance from conductor can be calculated as referred in IEC 60071-1 and other international practices.

6.2.3 Lightning overvoltage

The air clearance under lightning overvoltage can be determined by the lightning impulse withstand voltage and the lightning performance criteria. The concurrent wind speed for lightning overvoltage is generally taken as 0 or a small value.

Under lightning overvoltage, the 50 % positive lightning impulse flashover voltage of air clearance shall not exceed the 50 % lightning impulse flashover voltage of clean insulator string, which can be calculated as referred in IEC 60071-1 and other international practices.

Annex D shows diagrams of 50 % lightning impulse withstand voltage over air clearance for typical setups of supports. See 6.5 for lightning protection design and measures.

6.3 Phase to phase spacing (Horizontal, Vertical)

The phase to phase spacing shall be determined so as to achieve minimum air gap requirements pertaining for power frequency withstand voltage, lightning impulse withstand voltage and switching impulse withstand voltage.

Details of calculation of phase spacing in different countries are given in Annex B.

6.4 Ground clearances – Statutory requirements, electric and magnetic field limits

Ground clearances shall be calculated according to the maximum sag. For transmission lines in heavy icing areas, the uneven ice loading on conductors and the sag increment arising from ice loads shall be calculated. The impact of plastic elongation of conductor after erection and errors resulting from design and construction shall also be considered.

For UHV overhead transmission line, ground clearances are primarily determined by power-frequency electric field intensity limitation of the ground.

Generally, the power-frequency electric field limits for AC transmission lines are determined by considering three aspects, respectively to prevent transient electric shock causing abnormal, prevent steady-state electric shock current larger than the let-go threshold, and limit harmful ecological effects due to long-term effects of electric field.

Although different countries or electric power companies have different requirements, as per ICNIRP guidelines, the maximum field strength is 10 kV/m under transmission line and 5 kV/m at the edge of ROW.

6.5 Conductor-earth wire spacing, shielding angle – Lightning performance criteria

The lightning performance criteria of transmission lines are SFFOR and BFR. For UHV transmission lines, the acceptable lightning flashover rate ranges generally from 0,1 to 0,5 flashovers per 100 km per year, which is lower than for EHV systems.

The lightning flashover rate of a transmission line can be calculated by summing up the lightning flashover rate of each sectionalized line. The principle to divide the line into several line sections is according to ground flash density of lightning, terrain along the line, the structure of the tower, and the soil resistivity.

In the SFFOR calculation, critical shielding current can be derived by EGM or LPM as well as other methods.

In the BFR calculation, the traveling wave method is recommended to simulate the transient process after lightning strike the earth wire or tower.

The lightning protection for UHV transmission lines shall be designed according to the nature of load and operation mode of the system in combination with the operation experience of existing local transmission lines, the intensity and density of lightning activity, topographic and geomorphologic characteristics as well as the soil resistivity of the local area. A proper lightning protection method shall be employed through technical-economic analysis after determining the lightning withstand level, including:

– Double earth wires shall be installed along the overall transmission line.
– For mountain areas and the areas with high ground flash density of lightning, the shielding angle should be further reduced, even to a negative angle according to the actual conditions of projects.

Lightning protection should be reinforced appropriately for the incoming and outgoing line section near the substation.

7 Insulation coordination, insulator and insulator string design

7.1 General

For insulation coordination, the calculated requirements should also be evaluated through experimental results. Present IEC standards, which are IEC 60071 (all parts), IEC TS 60815 (all parts), etc., include basic principles of insulation coordination, but this document specifically refers to UHV AC transmission lines.

7.2 Insulation requirements – electrical design considerations

The insulator strings for transmission lines should be able to withstand the continuous operating voltage under the corresponding SPS, as well as the specified switching and lightning overvoltage.

In various SPS, USCD of insulators should be determined and be certified by withstand test in fog according to designed pollution requirements. The creepage distance effective factor is closely related to insulator profiles, which is derived from both pollution flashover characteristics and contamination accumulation characteristics of insulators. Therefore, in order to ensure reasonable insulation design of an UHV project, application of specific creepage distance method require more operating experience and test data.

Possibility of adopting high-performance circuit-breaker and surge arresters to reduce over-voltages may be examined to optimize insulation requirement of transmission line.

7.3 Insulating materials, type of insulators

Porcelain, toughened glass and composite insulators are mainly used in UHV AC transmission lines. The materials and type of insulators should be determined through techno-economic comparison based on engineering features, contamination and humidity characteristics along the lines as well as analysis of dust accumulation characteristics, and strengths and weakness in construction, operation and maintenance of insulators of various types.

The insulating parts of porcelain and glass insulators resist aging, corona, arc erosion and chemical corrosion but they are easily wetted and conduct leakage current that varies with accumulated pollution level. Besides, glass insulators have the feature of self-explosion (self-shattering) while the resistance is low. Compared with ceramic insulators, composite insulators are lighter and hydrophobic. The silicone rubber coatings applied to ceramic insulators offer some advantages of both ceramic and composite insulating materials.

The following factors can also be taken into consideration in selection of insulators:

– Additional measures such as application of RTV coating may be required when porcelain or glass insulators are used in coastal areas, salt lake, salt-treated roadway or other heavily polluted areas.
– Composite insulates, that can retain hydrophobicity and hydrophobicity transfer performance through pollution layers in all temperature, are easier to operate and maintain in areas with moderate or high site pollution severity.
– In heavy icing areas, measures against icing flashover like alternate-diameter strings, V-type and inverted-V-type insulator strings can be used for minimizing the probability of bridging of insulators through icicles and the probability of icing flashover.

7.4 Insulator string configurations for disc type insulators

Either specific creepage distance method or contamination withstand method may be used for determining the number of insulators in polluted conditions.

When the specific creepage distance method is used, the number of insulators is determined using the formula below:

$$n \geq \frac{\lambda V_{\mathrm{m}}}{\sqrt{3} K_{\mathrm{e}} L_{\mathrm{I}}} \qquad (1)$$

where

n is the number of insulators required for each string;

λ is the USCD [mm/kV];

V_{m} is the maximum system operating voltage [kV];

K_{e} is the effectiveness factor for creepage distance of insulator. It is mainly determined by the effectiveness of improvement of the withstand voltage under polluted conditions through the geometrical creepage distance of various insulators under test condition and operation condition;

L_{I} is the geometric creepage distance of a single suspension insulator [mm].

NOTE 1 This is a simplified calculation formula result in the number of insulators from the total creepage distance required and the geometric creepage distance of a single suspension insulator. The specific factor K_{e} indicates the performance of specific insulator in certain pollution environments, the description of the effectiveness of insulators are different in different countries. IEC 60815 can be referred for selection of pollution conditions and insulators creepage requirements.

NOTE 2 Configuration of insulator strings such as parallel arrangement of insulators will influence the pollution performance.

When the pollution flashover withstand voltage method is used, the number of insulators is determined using the formula below:

$$n \geq \frac{V_{\mathrm{m}}}{\sqrt{3} V_{50\%} (1 - n\sigma)} \qquad (2)$$

where

n is the number of insulators required for each string;

V_{m} is the maximum system operating voltage [kV];

$V_{50\ \%}$ is the pollution flashover voltage of a single insulator, [kV].

It can be the value corrected on the basis of the pollution flashover voltage obtained through tests against the actual natural conditions and after fully considering such factors as the pollution composition, non-uniformity of pollution on top and bottom surfaces, and NSDD based on test values of pollution flashover voltage of the insulator and according to practical natural conditions;

n is the multiple of standard deviation;

σ is the standard deviation of pollution flashover voltage of insulator, generally 3 % – 10 %.

NOTE 1 Correction of ESDD: If ESDD is equal to or smaller than 0,1 mg/cm^2, no correction is required; if ESDD is greater than 0,1 mg/cm^2, a coefficient K_{c} can be used for correction (K_{c} = 1-1,13 M^{2,57}, where M is the equivalent concentration of Ca^{2+} in composite salt). If the corrected ESDD is smaller than 0,1 mg/cm^2, it can be taken as 0,1 mg/cm^2.

NOTE 2 Correction of non-uniformity of pollution on top and bottom surfaces: the correction factor increases from 1,04 to 1,1 as the ESDD gradually increases.

NOTE 3 Correction of NSDD: The correction factor decreases from 1,22 to 1,04 as the ESDD increases gradually.

NOTE 4 This is a simplified calculation formula with statistical probability and deviation result in the number of insulators from the total required pollution flashover withstand voltage and the pollution flashover withstand voltage of a single suspension insulator.

7.5 Mechanical design criteria of insulator strings and associated hardware fittings

For mechanical design of insulator strings and hardware fittings in various conditions, everyday stress, ultimate load, string breakage load, etc., with adequate factor of safety should be considered.

The first fitting which connects to the crossarm should be able to rotate flexibly and should be rational in member stressing.

Voltage-sharing and anti-corona measures shall be taken for both insulator strings and fittings for UHV overhead transmission line.

Rigid type jumper wire is more applicable to strain towers.

Half of the angle between the branches of suspended V-shape strings of transmission lines may be less than maximum swing angle under wind condition considering slackness ranging from 5°~15° in one of the V-arms or may be determined through tests.

For transmission lines in heavy icing areas, when double insulator strings are used, the two strings should be suspended at one point. The conductors and earth wires of such lines should be protected with preformed armor rods, to mitigate or prevent damage to conductors and earth wires due to unbalanced tension, ice-shedding induced line jumping and galloping.

The spacing between strings for multi-string insulators shall be increased appropriately to minimize the likelihood of collision between strings due to vibration of insulator strings when ice-shedding induced line jumping occurs.

8 Bundle-conductor selection

8.1 General

As one of the most important components of transmission lines, conductors are expected to fulfil the main function of lines: transmit power, operate safely and reliably, and meet environmental protection requirements.

In principle, the following factors should be comprehensively taken into consideration in the selection of conductors:

- Transmission capacity of the system;
- Permissible temperature rises of conductors;
- Electric field effect;
- Environmental impacts including audible noise, radio interference and so on;
- Mechanical strength required;
- Special environmental requirements, such as pollution, anti-corrosion;
- Cost effectiveness considering the economic and service life.

8.2 Conductor types

In general, the types of conductors used in transmission lines include AAC AAAC, ACAR, ACSR, AACSR, ACSS, SS, etc.

At present, ACSR has been most widely used in UHV overhead transmission lines and its experience in design, manufacture, construction and operation aspects is matured.

AACSR has high tensile strength and low sag characteristics. Therefore, it can be used in large span, heavy ice area and other lines which require high strength and low sag characteristics of conductors.

8.3 Bundle conductor configurations

8.3.1 Number of sub-conductors

To reduce corona discharge in UHV overhead transmission lines, it is generally necessary to increase the number of sub-conductors and increase the conductor cross-section. Typically, minimum 8-bundle conductors are generally adopted in UHV AC transmission lines.

8.3.2 Bundle spacing

The selection of conductor spacing should consider the subspan oscillation and electrical characteristics of the bundle conductors. Generally speaking, problems caused by subspan oscillation can be avoided when the bundle spacing is large enough. From the electrical aspect, there is an optimum bundle spacing, in which the maximum electric field intensity on the surface of the conductor is the smallest.

Generally, for UHV AC transmission lines, the ratio of the bundle spacing to the diameter of sub-conductors (S/d) is not less than 10.

8.4 Conductor bundle selection process

8.4.1 Cross-section of conductor

The conductor should be capable of carrying the current corresponding to the required power flow, as well as the short-circuit current. In addition, the effects of electromagnetic environment are more prominent for UHV AC transmission lines. Therefore, electromagnetic environment criteria, in addition to ampacity requirement, should be considered for selection of the cross-section of conductor and number of sub-conductors.

8.4.2 Conductor ampacity

The mechanical strength of conductors may be degraded when the temperature rises to a certain level, therefore, the heating of conductors should be controlled. The maximum allowable conductor temperature under the ampacity rating corresponds to the long-term continuous operation, which is related to the conductor material and is determined by the residue of mechanical strength after long-term operation. It may be listed in standards or technical codes or can be determined with reference to guaranteed values due to product tests.

The minimum cross-section required for conductors can be calculated with the current required, the temperature allowed and the duration. The conductor ampacity can be calculated based on the heat balance principle.

The allowable ampacity of overhead transmission line conductors can normally be calculated by Formula (3).

$$I = \sqrt{\frac{q_{\mathrm{c}} + q_{\mathrm{r}} - q_{\mathrm{s}}}{R\left(T_{\mathrm{c}}\right)}} \qquad (3)$$

where

I is the ampacity rating of conductor (A);

q_c is the convected heat loss rate per unit length of conductor [W/m];

q_r is the radiated heat loss rate per unit length of conductor [W/m];

q_s is the heat gain rate from sun per unit length of conductor [W/m];

$R(T_c)$ is the AC resistance of conductor at T_c [Ω/m].

NOTE The detailed calculation of conductor ampacity can be referred to IEEE Std 738™-2012. The environmental conditions (wind speed, sunlight intensity and ambient temperature, etc.) and the conductor parameters (the resistivity, heat absorption coefficient, radiation coefficient, allowable temperature and diameter of conductor, etc.) are key factors of conductor ampacity. Among these factors, the wind speed, ambient temperature and maximum allowable conductor temperature also have a greater impact on the ampacity. For environmental conditions, meteorological data collected in various regions or empirical design values are generally used.

Refer to CIGRE 299 for more details. DC to AC conversion factors are based on skin effect and core-magnetisation effect in ACSR conductors.

8.4.3 Requirements for electromagnetic environment

The electromagnetic environmental impacts induced by high-voltage transmission lines include power-frequency electric field and magnetic field, as well as radio interference and audible noises resulting from corona of conductors. They affect the human's living environment and quality to a certain extent. Since UHV transmission lines have ratings for voltage and current, the effect of electromagnetic environment is more severe than other lower ratings.

The outer diameter and bundle configuration of conductors will affect the electromagnetic environment of UHV overhead transmission line. The configuration of conductors determined in designing of transmission line should meet the requirements of local laws and regulations for electromagnetic environment such as electric field intensity, radio interference and audible noise.

Annex E shows the restrictions on electromagnetic environment of UHV lines in different countries and Clause 11 will show more detail of it.

8.4.4 Capital cost and loss evaluation

For transmission lines, the cross-section of conductors affects both the construction investment and the operating electric energy losses. When analyzing the cost-effectiveness of the conductor scheme, the local conditions should be taken into account. Generally, besides the construction investment, the costs of electric energy losses including resistance heating losses and corona losses, operation and maintenance costs and time value of funds should be considered as well. The comparison of conductor schemes should be taken out in terms of cost-effectiveness throughout the economic and service life.

Present value cost method and annual cost method are two most commonly used methods for the economic comparison of conductor schemes for a transmission line project within the economic and service life. The principles of them are same, and the scheme with a lower present value cost or a lower annual cost will be preferred.

8.5 Mechanical strength

For mechanical characteristics, conductors are required to demonstrate appropriate mechanical performance and safety margin.

To protect conductors from mechanical breakage or fatigue damage, the conductor tension is generally limited from two aspects, i.e., the maximum allowable working tension and EDS.

The reliability for conductor tension under the checking condition of extreme (accidental) loads may be smaller than that under the normal design load condition. While for large-span lines crossing important rivers, or lines passing through areas where traffic conditions are extremely inconvenient, the design reliability may be increased appropriately since repair of the lines will be very difficult.

8.6 Conductor accessories

8.6.1 General requirements for fittings

The fittings of UHV transmission lines should meet local laws and regulations and with consideration of transportation, installation, maintenance and replacement. The general requirements are as follows:

– The fittings should have high reliability to maintain the safe and stable operation of transmission lines;

– The structure of fittings as well as the structures connecting the fittings with insulators, conductors and other fittings should be reasonable and optimally designed;

– In selection of materials, the requirements specified above shall be fully considered, and decision be made through comprehensive comparison from the aspects of strength, cost, workability, etc.;

– For fittings with the corona issue, the basic requirement that no visible corona under the highest power frequency voltage should be satisfied;

– The fittings should be interchangeable for ease of line maintenance;

– The fittings should also have provisions for live line maintenance such as holes and notches on yoke plates.

Other general requirements for transmission line fittings can refer to IEC 61284.

8.6.2 Type and design features of link fittings, vibration dampers, spacers

8.6.2.1 MSC joints

General requirements for link fittings can refer to IEC 61284.

8.6.2.2 Spacer

As a key component of protective fittings, spacer plays four main roles in the transmission line:

– prevent the collision of sub-conductors caused by short circuit current;

– suppress the subspan oscillation;

– reduce the severity of aeolian vibration;

– fix the relative positions of sub-conductors in a bundle.

The spacers are divided into rigid spacers and flexible spacers. Flexible spacer is usually divided into two types according to their damping forms: rubber damping and spring damping. It is appropriate to select rubber spacer damper, which are effective in restraining aeolian vibration and subspan oscillation.

Since UHV transmission lines are more liable to have oscillation problems in comparison to other ratings, damper spacers are required to be adopted. The damper spacer should be unequally spaced and asymmetrically arranged.

The general requirements of spacers can refer to IEC 61854.

8.6.2.3 Vibration damper

The general requirements of vibration damper can refer to IEC 61897.

Experiences of various countries on anti-vibration measures for conductors and earth wires of UHV transmission lines can refer to Annex F.

9 Earth wire/OPGW selection

9.1 General

In addition to the purpose of lightning protection, earth wires can also reduce secondary arc current, power frequency overvoltage of asymmetrical short circuit, interference to other communication lines, and can serve to carry optical fibres. The selection of earth wire should meet the mechanical, electrical and other requirements.

9.2 Type of earth wire/OPGW

In general, galvanized steel strand and aluminium clad steel strand are commonly used for overhead earth wire. As for UHV AC transmission line, aluminium clad steel strand or composite strand were widely used for OPGW.

The common structural types of OPGW are aluminium tube, stainless steel tube and aluminium skeleton.

IEC 60794-4-10 shows more details about the general requirements and test methods of OPGW.

9.3 Design Criteria/Requirements Specific to UHV Lines

See Annex G for more regulations on earth wires of UHV AC transmission line. It should meet the following basic requirements:

– strong overload capacity;
– vibration protection;
– good electrical performance;
– requirements of thermal capacity in terms of short circuit current and OPGW shunt current;
– the corona of the earth wire needs to be checked;
– excellent optical communication performance;
– sufficient lightning resistance;
– good vibration resistance and corrosion resistance.

NOTE The UHV transmission line has relatively larger span and higher suspension point of conductor/earth wire, which increases the severity of aeolian vibration and thus needs to be carefully designed in terms of anti-vibration. The material of earth wire should have good corrosion resistance. Typically, aluminium clad steel strand is a good choice for OPGW.

9.4 Induced voltages on earth wire

The magnitude of the induced voltage of earth wire is related to system unbalance, transmission power, segment length of insulated earth wire and the arrangement of conductors and earth wire, etc. Induced voltage in earth wire may cause energy loss and reduce the life of earth wire. Because of the high voltage level of UHV transmission line, the influence of earth wire loss will be more significant.

Some measures can be taken to reduce the induced voltage of earth wire for UHV transmission line, such as sectional insulation of earth wire, increasing the diameter of earth wire and double split earth wire.

10 Tower and foundation design

10.1 General

Towers are the vital component of overhead transmission lines and constitute a major portion of the total capital cost of transmission line. Towers are the main support structures for transmission line conductors carrying power. These are designed such that all the electrical clearances are maintained and all climatic and self-loads under different conditions on various components like conductors, earth wires, insulators, hardwares and on tower body are sustained to the desired levels of reliability, security and safety. As number of overhead lines over period of time have increased, public has become more conscious of the environmental impact of towers including land use and aesthetics. It is important to look into these aspects on case to case basis specially in case of UHV overhead lines where towers are large and tend to occupy larger portion of land besides increased right of way/corridor requirements due higher electrical clearances.

Foundation of a transmission line structure plays an important role in safety and satisfactory performance of the structure as it transmits mechanical loads of the electrical transmission system to earth. Transmission line foundations are the interlinking component between the support and the in-situ soil and/or rock. However, unlike the other major components of a transmission line, they are constructed wholly or partly in-situ in a natural medium whose characteristic geotechnical properties may vary in different locations depending upon geological, terrain and other different locational/site conditions. A transmission structure needs to have a sound and safe foundation to effectively perform the functions for which it has been designed.

As UHV transmission systems generally carry large amount of power and any momentary outage in such systems tend to have important bearing on the reliability and stability of the transmission grid, the transmission line towers need to have appropriate tower configuration and geometry and should be designed with high levels of reliability.

See Annex C for more detail of construction practice of foundation and tower.

10.2 Tower classification

10.2.1 General

Transmission line towers are broadly classified or designated based on conductor configuration, constructional features, line deviation angles etc.

10.2.2 Conductor configuration

In general, depending upon transmission line voltage level and number of circuits, various configuration of towers are possible and adopted world-wide. These include mainly:

a) **Vertical or Barrel type configuration:** Such type of configurations, involving vertical arrangement of phase conductors, are prevalent in single circuit, double circuit as well as multi-circuit transmission lines. In case of single circuit tower configurations, while the top phase is placed either on a crossarm projecting from one side of tower or on tower cage itself (in case of tension structures), the bottom two phases are placed on crossarms projecting from either side of the tower. In case of double circuit or multi-circuit towers, each of the phases of the towers are placed in vertical formation on crossarms projecting from either side of the tower. See Figure 1, Figure 2, Figure 7 and Figure 9.

b) **Horizontal or Wasp Waist type configuration:** In such type of configurations, phase conductors are placed horizontally at the same level on the boom of the tower. See Figure 3 and Figure 8.

c) **Delta or Cat Head configuration:** Such type of tower configurations are characterised by racket like head where phase conductors are placed in delta formation. See Figure 4.

d) **H-Structure Configuration:** Such configurations consist of two separate tower bodies connected with a boom at the top to hold the phase conductors, generally in a horizontal formation. See Figure 5 and Figure 10.

e) **Danube or Double-delta Configuration:** Such type of configuration has two crossarms. While the upper crossarms carry one phase on each side, the lower crossarms carry two phase on each side such that the phase conductors of each circuit are arranged in delta formation. See Figure 6.

IEC

Figure 1 – Typical single circuit vertical configuration tower

IEC

Figure 2 – Typical double circuit vertical configuration tower

IEC

Figure 3 – Typical single circuit horizontal configuration tower

IEC

Figure 4 – Typical single circuit delta configuration tower

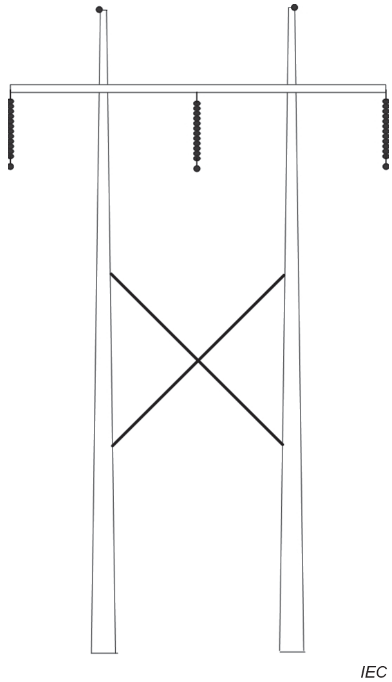


Figure 5 – Typical single circuit H-type tower

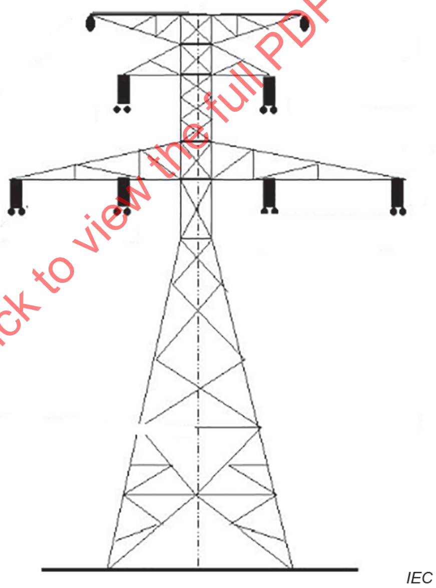


Figure 6 – Typical double circuit danube configuration tower

Figure 7 – 1 200 kV single circuit vertical configuration tower

Figure 8 – 1 200 kV single circuit horizontal configuration tower

Figure 9 – 1 200 kV double circuit vertical Configuration tower

Figure 10 – 1 200 kV single circuit H-type tower (for gantry)

In case of UHV overhead lines, which are generally single or double circuit, keeping in view the tower geometry and hexagonal/octagonal conductor-bundle requirements, the preferred type of configuration of towers is horizontal/delta (for single circuit lines) and vertical (for double circuit lines).

In view of higher reliability requirements for UHV lines, tower configurations with more than two circuits should be avoided.

10.2.3 Constructional features

From constructional point of view, the overhead line towers are generally classified as self-supporting towers or guyed towers.

a) **Self-Supporting Towers:** Self-supporting lattice steel towers are generally fabricated using steel sections or steel tubes of tested quality. The material used is generally mild steel having yield strength of about 250 MPa and high tensile/micro-alloyed high strength steel having yield strength of 350 MPa or above. These towers are designed either broad-based or narrow-based depending upon requirements and site conditions/constriants. While broad based self-supporting towers usually have square/rectangular base with four separate footings, narrow based towers may have combined monoblock footings depending upon overall economy. Steel monopoles which are sometimes used in EHV class lines may not be techno-economically suitable or feasible due to heavy load requirements.

b) **Guyed Towers:** Guyed towers are those that combine rigid elements such as lattice beams, masts or frames with pre-stressed guy wires resulting in stable economic and structural systems. These towers tend to consume lesser steel vis-à-vis self supporting towers. Guyed towers are generally used as suspension supports and for other support functions in such lines, self-supporting towers are used. Depending on the arrangements proposed among the rigid elements and the wires, guyed supports can be of V-Guyed Type, Portal Guyed Type, Cross-Rope/Chainette Suspension type, Lattice Guyed Monomast. As guyed towers including guy anchors occupy much larger land as compared to self-supporting towers, these types of towers find application in long unoccupied, waste land, bush tracts etc in plain terrain and may not be advisable for towers in agricultural fields, large inhabited areas and in hilly terrains (where placement of guys is difficult and impractical).

For UHV class overhead transmission lines, self-supporting towers have been mostly used.

10.2.4 Line deviation angle

Transmission line is generally routed cross-country from one place to another, passing through different areas, terrains and constraints. As route of transmission line is seldom straight, to optimize the cost and as part of standardization to have manageable number of designs, towers are further divided into (a) Tangent (also called suspension) and (b) Angle (also called tension) towers.

a) **Suspension or Tangent Towers:** The main function of these towers is just to suspend or support the conductors in alignment or with small line angles. These towers are used on the lines for straight run or for small angle of deviation. Conductor on suspension towers may be generally supported by means of I-String,V-String or Y-String.

b) **Anchorage or Tension Towers:** In such type of towers, conductors are anchored using tension insulator sets. Generally, these towers are designed to support maximum design conductor tension. Tension towers are used at locations where angle of deviation exceeds that permissible on suspension towers and /or where the towers are subject to uplift loads. These towers are used according to the angle of deviation of line.

10.2.5 Tower extensions

Transmission line towers are generally designed so that suitable height body/leg extensions can be added standard height towers without reducing strength/safety factor in members. These extensions are generally required and decided during tower spotting and optimisation of locations to maintain adequate clearances to ground and other obstructions along line route. The extensions can be of standard heights such as +3/+6/+9 meter etc. as per prudent utility practices. During crossing of overhead line with other overhead line or railway line or road highways, rivers etc., higher extension towers viz. +12/+18/+25/+30 m etc. or special rowers are required to be used and these should be designed accordingly besides taking other specific measures as per Regulations/prudent practices in different countries.

10.2.6 Specific requirements

a) **Transposition Towers:** Transposition towers are used to transpose the phase conductors in three sections in such a way that each phase by rotation occupies each of the three phase positions in a circuit. Generally transposition of phases are required for the line length above 100 km or as per system studies. While carrying out the transposition arrangements, availability of adequate electrical clearances should be ensured.

b) **Special Towers:** These towers are used at locations such as those involving long span river and valley crossings, cable termination towers, etc. which are specially designed to meet the site specific requirements.

10.3 Tower design

10.3.1 General

Transmission line towers are designed according to IEC 60826 and relevant Regulations and National/International standards of respective countries, based on primary line design data and available climatic data.

The tower design methodology should generally be as follows:

10.3.2 Selection of tower geometry based on electrical clearances

Primary objective of transmission line tower is to maintain safe electrical distances. Based on electrical clearances and circuit requirements a suitable geometry of a particular classification or type of tower is chosen. Sometimes tower geometry is also decided considering other requirements like narrow base available for construction and reduction in ROW. For higher altitudes clearances requirements do increase as per relevant standards and hence for such cases new towers are designed suitability.

As the transmission line voltage in case of UHV class transmission lines is much higher, the requirement of ground clearance, live metal clearances, mid span clearances, length of insulator strings, earth wires etc., also increased, and these are important parameters for deciding tower geometry.

10.3.3 Calculation of loads on tower

The overhead transmission lines are subjected to various loads during their life span which are generally classified into three distinct categories:

a) Reliability requirements: Climatic loads under normal condition

IEC 60826 specifies three different reliability levels for design of transmission lines i.e. Reliability Level-1 (corresponding to 50 years return period loads), Level-2 (corresponding to 150 years return period loads) and Level-3 (corresponding to 500 years return period loads).

In case of UHV transmission lines, the design should be done for appropriate reliability levels considering importance of the transmission line and/or to meet the specific requirements in respective country.

b) Security requirements: Failure containment loads under broken wire condition

These requirements correspond to measures intended to reduce risk of uncontrollable progressive (or cascading) failures that may extend well beyond an initial failure. Anchor towers should be designed for Anti-cascading condition.

c) Safety requirement based on mandatory regulations, construction and maintenance loads

Loads on tower under normal conditions are mainly based on wind speed/pressures, ice accumulation (if any), spans, reliability levels, size and weights of components (e.g. conductor, earth wire, insulator etc.)

The wind speed is considered as per wind map or wind data of the area as per prevailing regulations/standards of respective countries/regions.

Wind pressure should be calculated considering reliability level, terrain category as per IEC 60826 or relevant standards. Factors like gust, drag coefficient etc. are considered depending on height, size as per the standard requirements. The point loads in each condition are calculated and combination of loads as per the standard specifications and provisions are generated.

For ice loads also, the estimation of icing and calculation of loads should be done based on available climatology data following the criteria stipulated in IEC 60826.

For design, the loading calculations are followed by determination of strength coordination amongst line components, selection of appropriate load and strength factors, calculation of characteristic strength requirements of components and design of line components for respective strength requirements.

10.3.4 Analysis using software

Transmission tower is an indeterminate structure and calculation of member forces is done through solving stiffness matrix. Tower is modelled and analyzed for the given loading conditions in the software. On the basis of analysis, forces in each member are evaluated under different loading conditions and accordingly the size/sections of the members are selected for every tower component. After design, single line diagram showing dimensions and various section sizes is developed. Based on single line diagram detailed structural drawings showing connection details etc. are developed. Based on these structural drawings component drawings (shop sketches) are developed. Tower fabrication is done according to these shop sketches and prototype assembly of tower is done to ensure smooth fitting. In case there are certain changes required during proto assembly and full scale testing, the same are incorporated in the final drawings/documents.

10.3.5 Full scale tower testing

Transmission line tower is a complex structure made of many elements and safety of all the elements/members is essential for safety of the tower. As such designs developed on basis of computer analysis they have to be verified and validated by full scale tower testing. A full scale prototype tower as per design is assembled and subjected to various combinations of loads in a test bed. Suitability of fabrication is also established through tower testing. The testing is done as per IEC 60652.

Transmission line towers are repetitive structures and hence these are normally standardized and used like a product. Each type of tower is designed, tested and then is used as per the requirements.

Based on respective country specific requirements, full scale tower testing can be omitted when employing the design and analysis methods, which are considered to have enough reliability for ensuring the strength of towers through previous tests or experiences.

10.3.6 Tower design methodology

The broad tower design methodology should be as follows:

1) Collection of primary line design data and available climatic data.
2) Selection of reliability level.
3) Selection of security requirements.
4) Selection of safety requirements based on mandatory regulations, construction and maintenance loads.
5) Calculation of loads based on the reliability, security and safety requirements
6) Determination of strength coordination amongst line components
7) Selection of appropriate load and strength factors
8) Calculation of characteristic strength requirements of components
9) Design of line components for above strength requirements

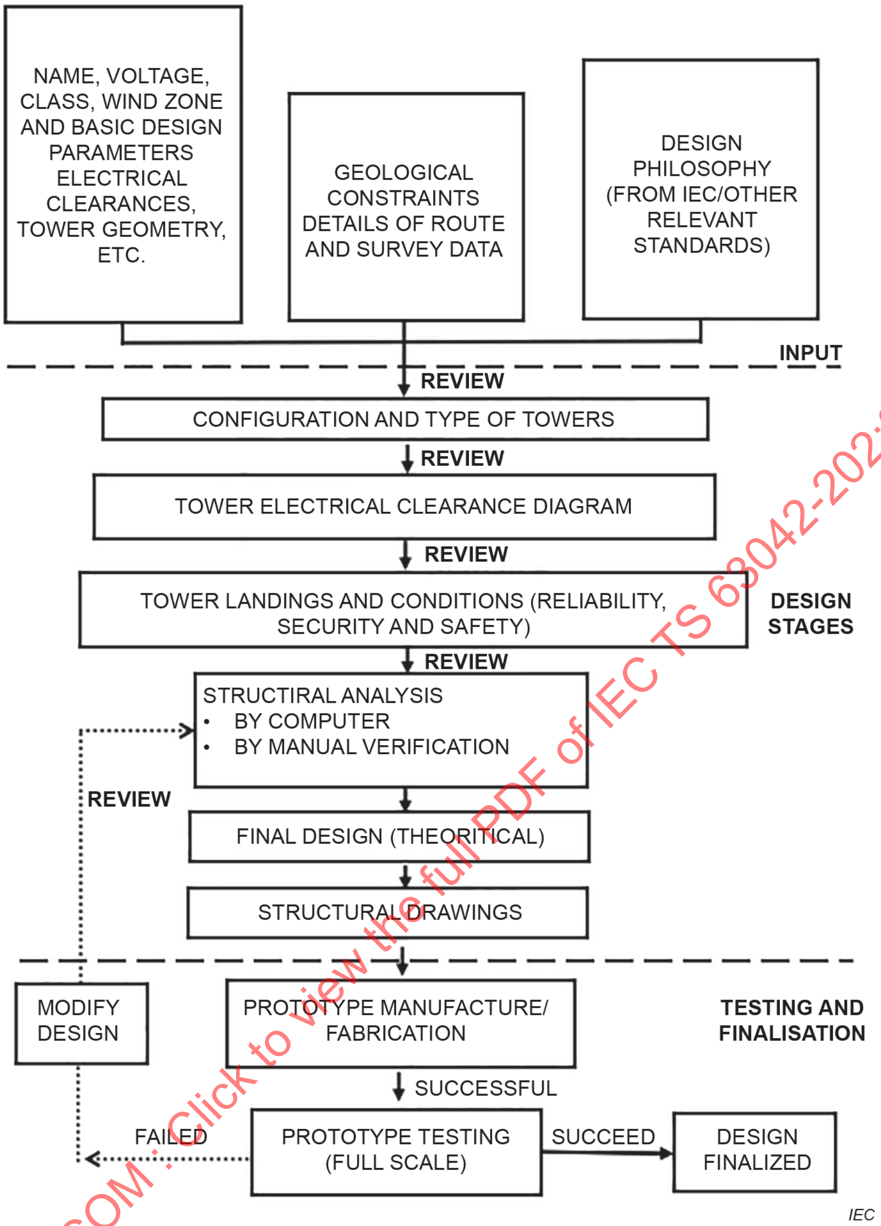


Figure 11 – Tower design methodology

10.4 Foundation design

10.4.1 General

Generally, foundations for buildings, etc. are subjected to large dead loads (mass) which result mainly in vertical compressive loads. The allowable movements of the foundations which support these types of structures are limited by the flexibility of the supported structures. Conversely, the forces acting on overhead transmission line foundations are typically due to overturning moment as a result of transverse, longitudinal and vertical loads of towers under different conditions.

In the case of separate foundations, individual foundation loads become a combination of uplift, compression and horizontal shear loads. These foundation loads arise primarily from dead load and a combination of wind and/or ice action on both the conductors and the support. The allowable displacements of the foundations must be compatible with the support types (lattice tower, monopole and H-frame supports) and with the overhead line function. Criteria for the damage and failure (ultimate strength) limit states for foundations, the relationship between characteristic strength and nominal strength of foundations, strength coordination between components and the methods of calculating the characteristic strength of the foundations (based on normal distribution) should be as per IEC 60826 or other country specific Regulations, standards, practices etc. The overhead transmission line tower foundations should be designed accordingly.

Transmission lines pass through different areas and terrains having soil/rock strata of different nature and variable local conditions. Yet conducting detailed geotechnical investigations for each and every location of a long transmission line and designing location specific foundation design is normally not practically feasible. As such, it is common practice to categorize and classify the types of foundations based on different nature of soil/rocks (cohesive, non-cohesive, clayey, sandy, fissured rock, hard rock etc.) and other soil conditions (dry, wet, submerged etc. depending upon ground water and submergence conditions) and prepare typical standard designs of these foundations for different types of towers considering typical soil properties and conditions. During construction stage, adoption of appropriate foundation type/design is decided based on available soil data and detailed investigations carried out at selected locations. For important tower locations (such as power line and other critical crossings, heavy angle towers, towers located in rivers/water bodies, marshy areas etc.), detailed geotechnical investigations are carried out at the particular location and location specific foundation designs are developed accordingly.

The types of foundations described in 10.4.2 to 10.4.4 are normally provided for transmission line towers depending on soil conditions, magnitude of loads, type of towers, etc.

10.4.2 Open cast type foundations

Open cast foundations are generally concrete pad and chimney type and are commonly used for overhead transmission line towers. Alternatively, steel grillage type foundations are also used in some countries. Normally open cast foundations are designed based on soil conditions and parameters considering ultimate foundation loads that are acting at the tower base (along the tower slope) viz. Down thrust (Compression), Uplift (Tension), Transverse side thrust and Longitudinal side thrust.

The magnitude of limit loads for foundations should normally be taken minimum 10 % higher than those for the corresponding towers. During design of foundations, the stability checks for appropriate safety during uplift, compression/bearing, sliding and overturning of the foundations are usually conducted besides the structural design of concrete/steel raft and chimney.

There are different categories of foundations which are designed depending upon the level of water table, soil type and its properties. The depth of these open cast foundations is generally 3 to 6 m. In case of aquifers are presented at lower depth below ground level and dewatering of foundation is very difficult and time taking. In such a case, shallow depth foundation with 2-2,5 m depth or raft foundation can also be designed.

10.4.3 Raft type foundations

A raft foundation, also called a mat foundation, is essentially a continuous slab resting on the soil that extends over the entire footprint of the tower, thereby supporting the tower and transferring its weight to the ground. A raft foundation distributes the weight of the tower over the entire area of the tower, and not over smaller zones (like individual footings) or at individual points (like pile/pier/well foundations). This reduces the stress on the soil.

These foundations are generally used under the following circumstances:

a) Low bearing capacity of soil.

b) Base of the tower is narrow.

c) Loads from tower are exceptionally high.

d) Infringement of isolated foundation due to narrow base width.

10.4.4 Deep foundations (Pile/Well/Pier/Steel Anchor type)

Deep foundations such as pile/well/pier/steel anchor type are also used in some countries depending upon site conditions, soil parameters, tower load requirements and prevailing construction practices.

These types of foundations are also recommended for transmission line towers located at the bank/mid-stream of river/water bodies or in the zone of where there is probability of scouring of soil around foundation. In such cases the individual well/pier or a group of piles are constructed up to 50 m deep in the ground and are designed such that the loads from the super structure are transferred to deep strata of soil safely.

11 Environmental considerations

11.1 General

The UHV AC transmission line is a system with high environmental performance which enables to transmit bulk power with low loss. On the other hand, the use of high voltage and large equipment may cause other environmental impacts as described in following clauses, thus appropriate measures should be taken to suppress them at the design stage. It is also necessary to satisfy the requirements in accordance with relevant regulations of each country and/or region.

This Clause 11 describes the impact of UHV AC transmission line on the external environment.

See Annex A for more detail of experimental results and considerations on environmental performance of UHV AC transmission line"

11.2 Electric field

11.2.1 General

The UHV AC transmission line adopts a high voltage and the electric field becomes strong accordingly. If the route is located in a place where the public may enter or near a communication line, appropriate measures should be taken as necessary.

11.2.2 Reference level of electric field

See ICNIRP "Guideline on limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz) 2010". According to this, the reference level of the electric field for public exposure is 5 kV/m at 50 Hz and 4,2 kV/m at 60 Hz. The reference level for occupational exposure is 10 kV/m at 50 Hz and 8,3 kV/m at 60 Hz. In addition to the above, set the levels of the following items as necessary:

a) Electrostatic stimulation

When a person comes into contact with an ungrounded metal object which is in the vicinity of a transmission line, the electric charge of the metal object flows through the human body. This may cause the human body to feel uncomfortable accompanied by electrical stimulation. Electrical stimulation is called electrostatic stimulation. For electrostatic stimulation it is difficult to set the levels, because of individual differences and frequency.

b) Communication failure due to electrostatic induction

When a communication line is located in parallel with and in the vicinity of a transmission line, a current due to electrostatic induction is generated in the communication line. Therefore, induced current should be restricted in consultation with the communication line administrator.

c) Induced voltage

When a communication line or a metal wire for a fence is located in parallel with and in the vicinity of a transmission line, a voltage is induced by a fault current or a load current of the transmission line. Therefore, induced voltage should be restricted in consultation with the facility administrator.

d) Malfunction of electronic devices due to electromagnetic field

Electronic devices may also malfunction if exposed to strong electromagnetic field. Therefore, both measures to reduce an electromagnetic field and to increase the resistance of devices are taken to ensure the normal operation of electronic devices. See parts of IEC 61000 for details.

11.2.3 Prediction of electric field

Electric field generated by a transmission line is predicted using the methods indicated in IEC 62110:2009, Annexes A and B.

Electric charge of metal objects in the electric field, current when human body comes into contact with the metal object, and the current induced in the communication line should be obtained by numerical calculation or experimental results.

11.2.4 Mitigation measures of electric field

In cases where influence by the electric field is predicted, the following measures should be taken appropriately to mitigate it:

– increase the height of conductor;
– for double-circuit transmission line, adopt reverse-phase arrangement to reduce the electric field on the ground;
– install shielding wires;
– ground the metal object or line so as to avoid accumulation of the electric charges and flow of induced current through human body;
– take measures for the communication line. It is often replaced with shielded metal line or optical cable.

11.3 Magnetic field

11.3.1 General

The magnetic field is determined by the current, not by the voltage. Therefore, handling of the magnetic field is same as for EHV. However, the magnetic field stress on the ground is smaller than that of EHV when the EHV and UHV currents are the same, because UHV requires bigger distances between live lines and surface of the earth due to higher voltage.

11.3.2 Reference level of magnetic field

UHV AC transmission line does not generate a strong magnetic field except special condition, the guideline provides the reference level of the magnetic flux density of 0,2 mT for the public exposure and 1 mT for occupational exposure. In addition to the above, set the levels of the following items as necessary.

11.3.3 Prediction of magnetic field

A magnetic field generated by a transmission line is predicted using the methods indicated in IEC 62110:2009, Annexes A and B.

11.3.4 Mitigation measures of magnetic field

The mitigation measures of the magnetic field are the same as the electric field. Therefore, when influence by the magnetic field is expected, the measures shown in 11.2.4 (Mitigation measures of electric field) are appropriately selected to mitigate it.

11.4 Corona noise (audible noise with corona discharge)

11.4.1 General

The voltage of UHV AC transmission line is so high that corona discharge is likely to occur and corona noise increase accordingly.

If the route is located in the vicinity of living area, it should be necessary to take measures that reduce corona noise.

11.4.2 Characteristics of corona noise

When the surface potential gradient of the conductor becomes high, corona discharge is generated on the surface of the conductor causing corona noise.

The condition of corona discharge is mainly determined by the surface potential gradient, but also changes by the surface state of the conductor, particularly in the rain. In case of light rain (rain rate of about 0,5 mm/h), many small water droplets are formed on the surface of the conductor, and corona discharge is easy to occur from the droplets. In case of heavy rain, the surface of the conductor is covered with a water film, and small water droplets are not formed. But strong corona discharge occurs when rain drops from the lower surface of the conductor. Corona noise in heavy rain is larger than in light rain. However, since background noise is low in light rain, corona noise in light rain often leads to complaints.

The surface potential gradient of the multiple conductors is large in the outward direction of the bundle. On the other hand, water droplets in heavy rain are generated on the lower surface of the conductor, the main source of corona discharge in the multiple conductors is the lower conductor where the direction of the surface potential gradient and water droplets coincide with each other.

Corona noise is a mixture of random noise and hum noise. The random noise is impulse sound when energy is released into space by corona discharge. It is white noise with a wide frequency band. The hum noise is generated when ions emitted into space by corona discharge are excited by the AC electric field in the vicinity of the conductor, and periodic pressure fluctuation when ions collide with neutral molecules is heard as sound. This sound is a low frequency where the commercial frequency and its double wave are dominant. When comparing the noise levels of random noise and hum noise, random noise is usually loud.

The corona noise generated from a single conductor shows the attenuation characteristics in inverse proportion to the distance. However, as for the hum noise, since it is sound of single frequency, waves generated from each conductor and waves reflected by the topography are superimposed, the noise level fluctuates due to the phase difference.

11.4.3 Reference level of corona noise

The tone and discomfort of corona noise are different from those of ordinary noise, and it is difficult to evaluate corona noise just by the noise level. It is to investigate the relationship between corona noise and complaints on existing transmission lines, and to set reference level to be lower than the noise level accepted by the public at the site where corona noise actually occurred.

Since corona noise fluctuates irregularly, L_5 (noise level when the time ratio exceeds 5 %), L_{50} (median noise level), L_{eq} (energetically averaged value of noise level), L_{dn} (energetically averaged value with noise level corrected by +10 dB(A) only at night) are useful in order to examine the relationship between noise level and complaints.

According to the examples of each country, the L_{50} below the conductor or several 10 m outside it at the time of heavy rain is often set at about 50 dB(A) to 55 dB(A), and complaints are received for corona noise higher than that. When a transmission line pass through areas with low background noise, strict reference level should be set.

11.4.4 Prediction of corona noise

The characteristics of the corona noise with respect to the surface potential gradient, the surface condition of the conductor, the distance from the sound source, and the like should be obtained in advance using numerical calculation or through experiments using corona cage or a test line. At this time, the conditions of light rain and heavy rain are required as the surface condition of the conductor. For information on a corona cage and a test line, see 5.2 of CISPR TR 18-1:2017.

By combination of the information above with rain data of the route, the level and probability of corona noise could be predicted.

11.4.5 Mitigation measures of corona noise

If complaints about corona noise are received or anticipated, the following mitigation measures can be adopted.

– Adopt multiple conductors to suppress the surface potential gradient. For the standard voltage of UHV AC transmission line, the corona noise would be mitigated to cause practically no problems by eight conductors. For more severe conditions, the number of conductors are increased. However, as the measure have significant effect on the tower weight and foundation volumes, number of conductors should be judiciously selected keeping cost into consideration.
– It is effective to narrow the spacing of only the lower conductors to suppress the surface potential gradient. The effect is several dB(A), but the cost of the measure is small.
– If it is necessary to reduce corona noise as a post-construction measure, install additional wire between two conductors on the lower side of the multiple conductors in the required section of the span to suppress the surface potential gradient. The corona noise would be mitigated several dB(A). In this case, the significant increase of tension load on the tower can be prevented by suspending the wire with spacers for conductors.

11.5 Radio interference with corona discharge

11.5.1 General

Similar to corona noise, radio interference is likely to occur caused by the high voltage of UHV AC transmission line. When the public uses mid-wave radio broadcasts in the vicinity of the route, it should be necessary to take measures to prevent radio interference.

11.5.2 Characteristics of radio interference

See Clauses 4 and 5 of CISPR TR 18-1:2017.

When corona discharge occurs on the surface of the conductor, a current pulse is induced in the conductor as the charge moves. The pulse radiates radio noise wave as it propagates through the conductor.

There are two types of corona discharge, positive corona and negative corona. The positive corona has high contribution to radio interference. The frequency characteristics of the positive corona show 1/f at 1 MHz or less, $1/f^2$ at 10 MHz or more, and the negative corona shows 1/f at several MHz or more. Therefore, AM broadcasting using medium waves is most susceptible to radio noise.

As the source of the radio interference is corona discharge, the effect of rain is same as described in corona noise. Radio interference increases with intensity of rain up to about 10 mm/h.

Since the current pulse due to corona discharge propagates far away, the radio interference may occur even if it rains far from the observation site.

11.5.3 Reference level of radio interference

See Clause 5 of CISPR TR 18-2:2017 and Clause 5 of CISPR TR 18-3:2017.

The reception quality of the radio is determined by the ratio of the signal level of the broadcast to the noise level (SN ratio). For AM broadcasting, the acceptable reception quality can be obtained when SN ratio is approximately 20 to 30 dB, but it is desirable to determine the reference level by conducting experiments because the feeling differs depending on the person. In case of FM (frequency modulation) broadcasting, since it has a characteristic that a stronger signal masks others, the reception quality would be maintained by suppressing the noise level less than signal level.

11.5.4 Prediction of radio interference

See Clause 5 of CISPR TR 18-1:2017 and Clause 7 of CISPR TR 18-3:2017.

The radio interference is obtained by experimental formulas according to voltage, conductor type and arrangement, the surface state of the conductor and the like.

11.5.5 Mitigation measures of radio interference

See Clause 4 of CISPR TR 18-3:2017.

When radio interference is anticipated, appropriate measures should be taken to reduce the noise. Similar to corona noise, it is effective for radio interference to take a measure of multiple conductors, arrangement of the lower conductors and additional wire.

Since the current pulse due to corona discharge propagates over several km, any measure does not effect enough unless it is applied to wide range.

11.6 Wind noise

Wind noise is generated from all parts of a transmission line, but wind noise from a conductor and an insulator lead to complaints especially, because a specific frequency would dominate. The UHV AC transmission line tends to generate louder wind noise than lower voltage class because multiple conductors and large insulators are adopted, and they are in high and windy position.

If the route is located in the vicinity of living area, it is necessary to take measures that reduce wind noise.

Annex A
(informative)

Experimental results and considerations on environmental performance of UHV AC transmission lines in different countries

A.1 General

Main experimental results and considerations on environmental performance of UHV AC transmission lines in different countries are respectively given in Clause A.2 (China), Clause A.3 (India) and Clause A.4 (Japan).

A.2 Experimental results and considerations on environmental performance of UHV AC transmission lines in China

A.2.1 Radio interference

Table A.1 gives the design limits for radio interference for AC transmission lines in China. The reference frequency is 0,5 MHZ and the reference distance is 20 m beyond the horizontal projection of the side phase conductor.

Table A.1 – Design limits for radio interference in China

Voltage (kV)	1 000
Limits (dB)	58

A.2.2 Audible noise

The design limits on audible noises from transmission lines vary from country to country. They are also implicitly specified in many local laws.

Although China and other countries have no standards for audible noise limitation of transmission lines, the local environmental protection authorities have formulated standards to limit the environmental noise. The audible noise limits of transmission lines should be in accordance with the local environmental noise limits.

Environmental quality criteria for noise in China is formulated with a view to ensuring the life quality of urban residents. It applies to urban areas, and can be used as reference for rural areas. The limits on environmental noises in the five categories of areas in cities specified in the standard are given in Table A.2.

Table A.2 – Criteria for environmental noises in the five categories of areas in cities (dB (A))

Category	Day	Night
0	50	40
1	55	45
2	60	50
3	65	55
4	70	55

NOTE 1 Category-0 areas refer to those such as sanitaria, luxury villas, and high standard hotels where quietness is specially required.

NOTE 2 Category-1 areas refer to those where residential buildings and cultural and educational offices are located. Standards for this category of areas can be used as reference for rural areas.

NOTE 3 Category-2 areas refer to mixed areas of residential areas, business and industry.

NOTE 4 Category-3 areas refer to industrial areas.

NOTE 5 Category-4 areas refer to those on both sides of trunk roads in cities and those on both sides of inland river channels passing through urban areas.

UHV transmission lines in China mainly pass through non-residential areas such as barren hills, woodlands or agricultural areas, which are classified in the category-2 areas referring to the noise limits listed in Table A.2. The audible noise L_{50} of UHV AC transmission lines should not exceed 55 dB(A).

A.2.3 Electric field

Based on the design and operation experience of UHV transmission lines in China, the limit of the maximum electric field in residential area and non-residential area is 7 kV/m and 10 kV/m respectively. For some sparsely populated non-agricultural areas, the limit can be increased to 12 kV/m.

A.3 Experimental results and considerations on environmental performance of UHV AC transmission lines in India

A.3.1 Electrical Clearances from buildings, structures, etc.

In India, horizontal and vertical clearances for transmission lines from buildings, structures, etc. are determined based on country regulations. For 1 200 kV UHVAC line, the clearances are as follows:

a) horizontal clearance: 12,8 m;
b) vertical clearance: 14,5 m.

A.3.2 Electric field

Based on ICNIRP Guidelines, maximum Electric field at 1,8 m height from ground is limited to 10 kV/m and electric field at edge of right of way, at 1,8 m height from ground, is limited to 5 kV/m.

For 1 200 kV UHVAC line in India, the values of the maximum electric field and electric field at edge of right of way are as follows:

a) max. electric field at 1,8 m height from ground: 9,8 kV/m;
b) electric field at edge of right of way (at 1,8 m height from ground): 4 kV/m.

A.3.3 Radio interference

For transmission lines in India, radio interference at the edge of right of way is limited to 40 dB/µV/m.

For 1 200 kV UHVAC line in India, radio interference at edge of right of way is 31,3 dB/µV/m.

A.3.4 Audible noise

For transmission lines in India, L5 audible noise levels at edge of right of way is limited to 58 dB(A) and L50 Audible Noise levels at edge of right of way is limited to 55 dB(A).

For 1 200 kV UHVAC line in India, audible noise levels at edge of right of way are as follows:

a) audible noise (L5 level): 58 dB(A);
b) audible noise (L50 level): 53,8 dB(A).

A.4 Experimental results and considerations on environmental performance of UHV AC transmission lines in Japan

A.4.1 General

UHV AC transmission lines in Japan are designed for environment in consideration of following items.

A.4.2 AN (audible noise)

a) Reference level

Reference level for AN is set as 50 dB(A) or less in light rain at a point of 3m outside under the conductor. The setting basis is as follows:

- in Japanese environmental regulations, the reference level for areas that require especially silence is set at 50 dB(A) during the day and 40 dB(A) during the night (see Table E.4);
- referring to operation results of 500 kV AC transmission lines, no complaints have occurred at points where AN is 52 dB(A) (case of 410 mm^2 × 4 with spiral rod) or 49 dB(A) (case of 240 mm^2 × 4).
- a sound insulation effect of a typical house is about 15 dB(A), and the reference level for night is satisfied with the effect.

b) Prediction methods

AN is calculated using following empirical formulas.

$P(G_i, n, d)$ is an experimental value of AN obtained by corona cage. Many experiments have been conducted to obtain data on various conductor configurations.

$$P_T = 10\log \Sigma 10^{P_i/10} \quad \text{(A.1)}$$

$$P_i = P(G_i, n, d) - 10\log r_i \quad \text{(A.2)}$$

where

P_T is the AN totalling all P_i [dB(A)];

P_i is the AN of i-th conductor (phase) [dB(A)];

$P(G_i, n, d)$ is the experimental value of AN determined by G_i, n, d [dB(A)];

G_i is the surface potential gradient of i-th conductor [kV/cm];

n is the number of sub-conductors per phase;

d is the diameter of sub-conductor [cm];

r_i is the oblique distance between conductor (phase) and measuring point [m].

c) Mitigation measures

The following measures are taken to reduce AN below the reference level:

- The conductor configuration of 8 × 610 mm^2 or more is adopted. See B.4.1 a) for details.
- For places where residences exist within 300 m of transmission line or where development is expected in the future, the tower configuration with wider phase interval than usual is adopted to reduce the surface potential gradient of conductors.(+2,5 m)
- If complaints still occur even after taking these measures, asymmetric conductor arrangement or additional wires will be adopted.

A.4.3 RI (Radio Interference)

a) Reference level

In the vicinity of transmission line, ratio of broadcast electric field intensity to radio noise intensity (S/N ratio) is set as 20 dBµV/m or more, or radio noise intensity is set as 60 dBµV/m or less. In either case, radio noise intensity is predicted under light rain conditions. The setting basis is as follows.

– According to the experiment, several percent of people judge radio reception quality as "noisy and unacceptable" when S/N ratio is 20 dBµV/m. Also, the incidence of light rain causing bad radio reception quality is only 1 % of the year.

– Referring to operation results of 500 kV AC transmission lines, no complaints have occurred at points where radio noise intensity is 60 dBµV/m (case of 410 mm^2 × 4).

b) Prediction methods

Radio noise intensity is calculated using following empirical formulas. N_p is calculated for each phase and the maximum value is used for design.

$$N_p = \frac{N_m - N_0}{(\alpha / p) \cdot (2{,}53 / d)^2 + 1} + N_0 \qquad \text{(A.3)}$$

$$N_m = 10{,}5G_p - 0{,}25G_p{}^2 - 31 + 40\log(2{,}53 / d) + 20\log(10h / D^2) - 12(\log f)^2 - 17\log f \qquad \text{(A.4)}$$

$$N_m = 9{,}5G_p - 0{,}16G_p{}^2 - 50{,}5 + 40\log(2{,}53 / d) + 20\log(10h / D^2) - 12(\log f)^2 - 17\log f \qquad \text{(A.5)}$$

$$\alpha = -0{,}16G_{max}{}^2 / G_p + 3{,}72 \qquad \text{(A.6)}$$

where

N_p is the radio noise intensity when rainfall intensity is p [dBµV/m];

N_m is the maximum radio noise intensity in rain [dBµV/m], in case of G_p ≤ 17 kV/cm;

N_0 is the radio noise intensity when rainfall intensity is 0 [dBµV/m];

p is the rainfall intensity = 4 [mm/h];

d is the diameter of sub-conductor [cm];

G_p is the vertical downward surface potential gradient of lower sub-conductor in bundle [kV/cm];

h is the vertical distance between conductor and measuring point [m];

D is the oblique distance between conductor and measuring point [m];

f is the frequency = 1 [MHz];

G_{max} is the maximum surface potential gradient [kV/cm].

c) Mitigation measures

When mitigation measures for AN are taken, the reference level for RI is satisfied.

A.4.4 EMF (Electromagnetic field)

a) Reference level

Electric field is set as the value shown in Table A.3 or less at 1m height around transmission line. The setting basis is as follows.

- The value of category A is as required by regulation.
- The value of category B is set as 5 kV/m, which could reduce electric field to 3kV/m by installing shielding wires even if development around transmission line proceeds in the future.
- The value of category C is set as 10 kV/m, which is assumed to have no effect on human health.
- Figure A.1 shows the results of sensing tests conducted in Japan assuming that a person is in contact with an umbrella. From this result, when electric field is at 3kV/m or less, people are rarely made uncomfortable.

The reference level of magnetic field is as in E.4.5, but the design which considered magnetic field was not performed when UHV AC transmission line was constructed. This is because the reference level is automatically satisfied without any special measures and because regulation on magnetic field was enacted after the construction of UHV AC transmission line.

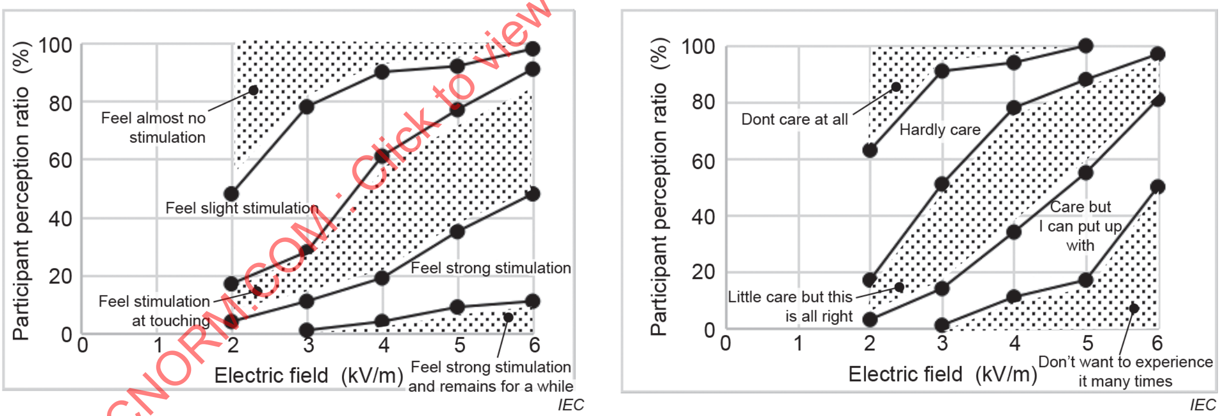
Table A.3 – Reference level of electric field and ground height of conductor

category	electric field [kV/m]	ground height of conductor [m]
A	3	42
B	5	32
C	10	25

category A: areas people can enter easily

category B: areas people are unlikely to enter but may enter in the future

category C: areas people rarely enter



(a) Degree to feel **(b) Degree to feel**

Figure A.1 – Results of sensing tests under transmission lines

b) Prediction methods

Electric field is calculated using the formula of JIS C 1911:2013, Annex A, Clause A.2, and magnetic field is calculated using the formula of JIS C 1911:2013, Annex B, Clause B.2. These are the same as IEC 62110.

c) Mitigation measures

Following measures are taken to reduce electric field below the reference level.

- Ground height of conductor is set as the value shown in Table A.3 or more.

– Reverse phase arrangement is adopted.
– In the area of category B, shielding wires will be installed in the future when development proceeds around transmission line.

As for magnetic field, no special measures are taken because the reference level is automatically satisfied.

A.4.5 Electromagnetic induction interference, Electrostatic induction interference

a) Reference level

Following failures occur in communication lines due to electromagnetic induction and electrostatic induction from UHV AC transmission line, and the reference level is set for each communication line operator.

– Overvoltage is generated on communication lines due to electromagnetic induction action from fault current of transmission line, and workers of communication line are in danger.
– Voltage is generated on communication lines due to electromagnetic induction action from load current of transmission line, and communication quality is degraded.
– Current is generated in communication lines due to electrostatic induction action, and communication quality is degraded.
– Space electrical potential above poles of communication line increases, and workers of communication line feel electrostatic shock.

b) Prediction methods

Current generated in communication lines due to electrostatic induction action is calculated using the formula of E.4.6. For other values, prediction methods are prepared for each communication line operator.

c) Mitigation measures

Following measures are taken when voltage or current of communication lines or space electrical potential above poles of communication line exceeds the reference level.

– Reduce ground resistance of communication line.
– Change the type of communication line to cable with sheath or optical fibre.
– Increase ground height of transmission line.

A.4.6 Wind noise from conductor

a) Reference level

When wind noise exceeds "background noise + 10dB(A)" at dominant frequency, possibility of leading to complaints will increase. However, in case of UHV AC transmission line, the reference level is not used to limit area where mitigation measures are taken to minimum necessary, but facilities are designed that measures can be installed when residences exist within 300 m of transmission line.

b) Prediction methods

Wind noise is calculated using following empirical formulas. α(d, s, n) is an experimental co-efficient obtained by wind tunnel. It represents the effect that, when two conductors are arranged in parallel, wake of the upwind conductor interferes with that of the downwind conductor to generate loud noise.

$$L = L_T + 30\log f - 39 \quad (A.7)$$

$$L_T = 10\log \Sigma 10^{L_i/10} \quad (A.8)$$

$$L_i = 10\log(10^{12} \cdot \frac{\alpha(d,s,n) \cdot \rho \cdot \mathrm{d} \cdot S^4 \cdot (U \cdot \sin\psi)^6}{2 \cdot C^3 \cdot r} \cdot \sin\frac{\theta}{2} \cdot \cos\xi) \tag{A.9}$$

$$f = 0{,}2(U / \mathrm{d}) \tag{A.10}$$

where

L	is the auditory-corrected L_T with A characteristic [dB(A)], in case of f ≤ 250 Hz;
L_T	is the wind noise totalling all L_i [dB];
f	is the dominant frequency of wind noise [Hz];
L_i	is the wind noise of i-th conductor (phase) [dB];
α(d, s, n)	is the experimental co-efficient determined by d, s, n;
d	is the diameter of sub-conductor [m];
s	is the spacing of sub-conductors [m];
n	is the number of sub-conductors per phase;
ρ	is the air density = 0,125 [kg/m^3];
S	is the Strouhal number = 0,2;
U	is the wind speed [m/s];
ψ	is the wind direction to conductor [deg];
C	is the sonic speed [m/s];
r	is the oblique distance between conductor(phase) and measuring point [m];
θ	as in Figure A.2 [deg];
ξ	as in Figure A.2 [deg].

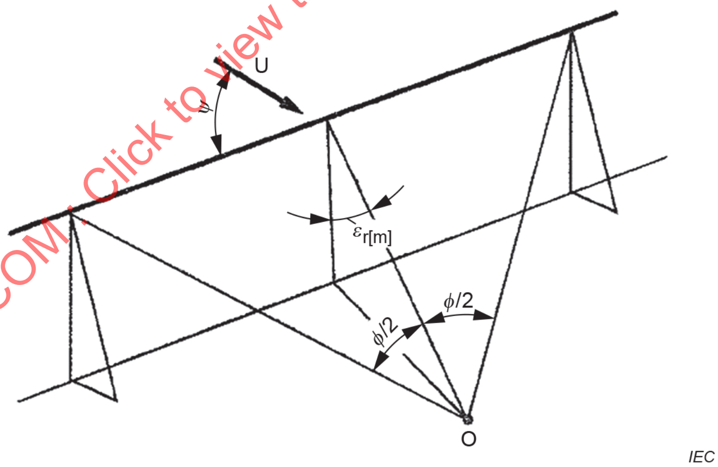


Figure A.2 – Symbols related to wind noise prediction formula

c) Mitigation measures

If wind noise occurs in actual and it leads to complaints, spiral rods are installed to conductors. In addition, when complaints are expected in advance, conductors of low-noise type (see B.4.1) are adopted.

A.4.7 Ice and snow falling from conductor

a) Characteristics of ice and snow falling of UHV AC transmission line

Although ice and snow fall from every part of transmission line, ice and snow falling from conductor lead to complaints because it scatters in wide range around the route. In case of UHV AC transmission line, in particular, complaints tend to increase for following reasons.

– As a result of adopting multiple conductors, current of sub-conductor is small so that the amount of heat is not enough to suppress ice and snow accretion.
– The amount of ice and snow accretion increases as number of conductor increases.
– Since conductors are located high and windy position, the falling distance from conductor is long and the range of ice and snow scattering is wide.

In Japan, the degree of ice and snow falling, the presence of complaints, and the acceptable level of the public at the site are comprehensively considered and dealt with in each case.

b) Prediction methods

The degree of ice and snow falling is predicted in consideration of following items.

– Type and amount of ice and snow accretion before falling changes with various conditions. It is difficult to predict, but data that determine ice and snow load of supports is used as reference.
– Size of falling varies depending on weather conditions, type of ice and snow, type of conductor. It is investigated using test lines and existing transmission lines.
– The area of scattering is roughly estimated by setting the wind, the size and weight of fallings, and the height of conductors. However, it would varies depending on the shape of fallings, it should be investigated using test lines and existing transmission lines.

The presence of complaints, and the acceptable level of the public at the site are estimated from results of existing transmission lines and field surveys around the route.

c) Mitigation measures

If complaints about ice and snow falling are predicted or occur, following measures are taken to mitigate damages by fallings. But ice and snow falling is a natural phenomenon, it cannot be completely controlled even with mitigation measures.

– Rings are installed on conductors or earth wires at intervals of several 10 cm. The ring has several millimetres thickness and width, and create weak points in strength of ice and snow accretion. When ice and snow accretion falls, it breaks at the position of rings, and size of ice and snow falling becomes small.
– LC spirals are installed on conductors. The LC spiral complements lack of heat from conductor to suppress development of ice and snow accretion. However, in case of UHV AC transmission line, current of sub-conductor is small, it may not generate enough heat.
– Water repellent coating or wrapping is applied on conductors or earth wires to reduce ice and snow accretion. The water-repellent effects generally last only a few years and regular maintenance is required.
– Counterweights are installed on earth wires. The counterweight is a device to prevent heavy ice and snow accretion, also effective to suppress the size of ice and snow falling.

A.4.8 Landscape impact

a) Landscape impacts of UHV AC transmission line

In Japan, landscapes have become one of the important concerns of the administration and local residents.

Landscapes designated as resources by the national or local landscape administration or by the environmental administration are especially required to be protected because they are visited for the purpose of viewing by people outside the area. In addition, when UHV AC transmission line comes into view in daily life, local residents feel intimidated and uncomfortable, so it is sometimes necessary to consider landscapes that are not designated as resources.

UHV AC transmission line is a large scale facility and is easily visible to the public. It has a different structure from other artifacts or natural objects, and spreads widely in a line, UHV AC transmission line is likely to undermine the value of landscapes.

When landscapes to be protected are around the route, the facility is harmonized with landscapes while listening to the opinions of the administration and local residents.

b) Prediction methods

Landscape impacts of UHV AC transmission line are predicted as following procedures. When the environmental impact assessment is required by law, procedures are carried out in accordance with relevant regulations.

– Select landscapes to be protected and corresponding viewpoints (places where you can see the landscapes) referring opinions of the administration and the public.
– Conduct on-site surveys of viewpoints and confirm actual usage of landscapes.
– Calculate a direction angle between the landscape and the transmission line from the viewpoint. In addition, confirm hidden parts by terrain and visible parts of the transmission line from the viewpoint, and a viewing angle is calculated for the visible parts. The direction angle and the viewing angle are indices quantitatively expressing landscape impacts of transmission line.
– Create a montage of landscape and transmission line from the viewpoint. A montage is a photograph of landscape taken from the viewpoint, or a topographical map obtained by a computer, overlaid with a graphic of transmission line, and shows the landscape after the completion of transmission line. The montage is a material sensuously expressing the landscape impacts of transmission line.

c) Mitigation measures

If necessary, the following measures are taken to harmonize transmission line with the landscape to a reasonable extent.

– The route is placed out of sight from viewpoints. Specifically, it is placed beyond hills or behind viewpoints.
– The route is placed where transmission line is not noticeable. Specifically, it is placed at the edge of view (increase the direction angle) or far from the viewpoints (decrease the viewing angle).
– The facility is fit to the background. Specifically, the route is placed on hillsides, and the colour and lightness of towers and wires will be the same as hillsides. If the route is placed on ridgelines, the presence of transmission line will stand out and undermine the value of landscapes.

A.4.9 Nature conservation

a) Nature impact of UHV AC transmission line

Nature is a finite resource that requires a long time to restore once it is destroyed. In Japan, endangered species, natural monuments, and nature preserves are designated, and activities to protect rare animals and plants, and the ecosystem are carried out at the national level.

UHV AC transmission line has a large scale and it has a considerable impact on Nature as follows.

– The rare animals and plants, and the ecosystem are damaged directly due to logging and topographical changing at the stage of construction.
– The rare animals dislike access of workers and noise of heavy machineries during construction, and would stop breeding.
– Conditions such as sunlight and soil moisture change due to logging and topographic changing, which indirectly affect rare plants.

– Main fields of activity of the upper species in the food chain are changed due to large scale logging and topographical changing, and lead to changes in the ecosystem.
– Transmission line is built on the flight path of rare birds and they may collides with it during flight.

b) Prediction methods

For UHV AC transmission line, impacts on the rare animals and plants, and the ecosystem are predicted as following procedures. When the environmental impact assessment is required by law, procedures are carried out in accordance with relevant regulations.

– Collect documents issued by the environmental administration such as the Red Data Book, maps of animals and plants distribution, maps of nature preserves, and investigate rare animals and plants, and the ecosystem near the route.
– Obtain more information from conservation groups and experts that are closely related to rare animals and plants, and the ecosystem.
– Survey the following items on the route and the construction sites. For animals, species, nest sites, main fields of activity, and breeding season are confirmed. For plants, species, accurate distribution, environment of habitat are confirmed. For the ecosystem, identify species closely related to the food chain and breeding of rare animals and plants, and upper species in the food chain at the site.
– Clarify the positional relationship between rare animals and plants, and the route for each species based on data obtained from documents and on-site surveys, and predict the impacts of the transmission line itself or the construction activities on rare animals and plants, and the ecosystem with the advice of experts.

c) Mitigation measures

When there exist rare animals and plants, and the ecosystem to be protected around the route, the following measures are taken to minimize the impacts and harmonize transmission line with Nature.

– The route is selected to avoid nature preserves.
– The route and the construction sites are selected to avoid the main fields of activity of rare animals and habitat of rare plants. If it is unavoidable, the route and the construction sites of less influential are determined in consultation with the environmental administration.
– Better nesting environment for rare animals is created artificially, and their main fields of activity is directed away from the route and the construction sites.
– The construction period is set to avoid the breeding season which requires special consideration for rare animals.
– Rare plants are transplanted to suitable areas outside the route or the construction sites. They are sensitive to changing of environment and the ecosystem, transplanting is carried out with the advice of experts.

Eye-catching colour tags or rings are installed to conductors. They make the rare birds aware of conductors and prevents them from colliding.

Annex B
(informative)

Design practice of UHV AC transmission lines in different countries

B.1 General

Design practice of UHV AC transmission lines in different countries are respectively given in Clause B.2 (China), Clause B.3 (India) and Clause B.4 (Japan).

B.2 Design practice in China

B.2.1 General

Yuheng-Weifang 1 000 kV AC transmission line project, which is still running since August, 2017, is elaborated as follow.

B.2.2 Conductor and earth wire

a) Conductor selection

With the consideration of many factors including the transmission capacity of the system, economic current density, the demands on energy saving and consumption reduction, and the requirements for electromagnetic environment, 8-bundle conductor with cross-section of 630 mm^2 and bundle spacing of 400 mm is adopted in this project.

The conductor types used in single-circuit lines and double-circuit lines on one tower in different icing areas are shown in Table B.1, the main characteristics are shown in Table B.2.

Table B.1 – Conductor type selection

<table>
<tr><th rowspan="2">Ice thickness</th><th colspan="3">Double-circuit line on one tower</th><th colspan="3">Single-circuit line</th></tr>
<tr><th>conductor</th><th>Incoming/outgoing line conductor</th><th>Tension tower flexible jumper</th><th>conductor</th><th>Incoming/outgoing line conductor</th><th>Tension tower flexible jumper</th></tr>
<tr><td>10 mm</td><td>8×JL1/G1A-630/45 (8×ACSR-630/45)</td><td rowspan="2">JLK/G1A-725(900)/40</td><td rowspan="2">JLK/G1A-725(900)/40</td><td>8×JL1/G1A-630/45 (8×ACSR-630/45)</td><td rowspan="2">JL1/G1A-630/45 (ACSR-630/45)</td><td>JL1/G1A-630/45 (ACSR-630/45)</td></tr>
<tr><td>15 mm</td><td>8×JL1/G1A-630/55 (8×ACSR-630/55)</td><td>8×JL1/G1A-630/55 (8×ACSR-630/55)</td><td>JL1/G1A-630/55 (ACSR-630/55)</td></tr>
</table>

NOTE 1 JL1/G1A is the Chinese definition method of Aluminium Conductors Steel Reinforced (ACSR) wire.

NOTE 2 JLK/G1A is the Chinese definition method of Expanded Diameter Aluminium Conductors Steel Reinforced (Expanded ACSR) wire.

Table B.2 – Conductor characteristics

Item	Type	JL1/G1A-630/45 (ACSR-630/45)	JL1/G1A-630/55 (ACSR-630/55)	JLK/G1A-725(900)/40
Structure Quantity / diameter	Aluminium	45/4,22	48/4,12	7/2,66
	Steel	7/2,81	7/3,20	27/3,99 11/3,99 11/3,99 91/3,99
Calculated section (mm^2)	Aluminium	630,0	639,92	725,21
	Steel	43,6	56,30	38,90
	Total	674,0	696,22	764,11
Overall diameter (mm)		33,8	34,3	39,9
Unit weight (kg/m)		2,0792	2,2064	2,3097
Nominal tensile force of conductor (N)		150 450	164 310	160 380
Elastic modulus (MPa)		63 000	65 000	61 870
Linear expansion coefficient (1/℃)		20,9 × 10 × 6	20,5 × 10 × 6	21,2E-6

b) earth wire selection

According to the requirement of system communication, two OPGW, one OPGW or ordinary earth wire are installed in different sections of the line.

By comprehensively considering such factors as icing overload capacity, vibration resistance, short current shunting capacity, ground wire surface gradient and corona onset gradient value, and lightning withstand performance, the earth wire for double-circuit line is recommended to be ACS-185 (20,3 % IACS) type aluminium-clad-steel strand and the earth wire for single-circuit line is recommended to be ACS-170 (20,3 % IACS) type aluminium-clad-steel strand. In accordance with the matching principle of OPGW and ordinary earth wire, the OPGW recommended for single-circuit line and double-circuit line are OPGW-170 and OPGW-185 respectively.

The ordinary earth wire is operating in the mode of subsection insulation and single-point grounding and the OPGW is grounded on each tower.

The design safety factor of the earth wire should be larger than that of the conductor.

c) phase to phase spacing

The horizontal separation can be calculated using the equation below for conductors with span length less than 1 000 m:

$$D_h = k_i \cdot L_k + \frac{U}{110} + 0{,}65 \cdot \sqrt{f_c} \qquad \text{(B.1)}$$

where

k_i is the coefficient for suspension insulator string, which should comply with the values listed in Table B.3;

D_h is the horizontal separation between phase conductors, m;

L_k is the length of suspension insulator string, m;

U is the system nominal voltage, kV;

f_c is the maximum sag of conductor, m.

The vertical separation between vertical phase conductors should be 75 % of the values obtained using this equation.

Table B.3 – Coefficient k_i

Type of suspension insulator string	I-I Type String	I-V Type String	V-V Type String
k_i	0,4	0,4	0

d) Anti-vibration measures for conductors and earth wires

Because of the vibration elimination effect of rubber spacer damper, vibration damper is not required for the ordinary span conductors. The vibration damper is installed in large span conductors.

Vibration dampers are commonly installed in earth wires depending on the upper limit of average operating tension and the span.

B.2.3 Electrical clearances

A typical example formula of power frequency voltage is given below:

$$U_{50\%} \geq K_s K_a K_c \sqrt{2} U_s / \sqrt{3} \quad \text{(B.2)}$$

where

U_s is the maximum system operating voltage (kV);

K_s is the safety factor, 1,05;

K_c is the coordination factor, 1,1;

K_a is the altitude correction factor.

NOTE 1 50 % is the occurrence probability of power-frequency flashover. $U_{50\ \%}$ is determined by the average value of multiple flashover experiments.

A typical example formula of switching overvoltage is given below:

$$U_{50\%} \geq K_s K_a K_c U_{e2\_sf} \quad \text{(B.3)}$$

where,

U_{e2_sf} is the value of the phase to ground switching overvoltage having a 2 % probability of being exceeded;

K_s is the safety factor, 1;

K_c is the coordination factor, 1,1–1,26 for I type insulator string, 1,27 for V type insulator string;

K_a is the altitude correction factor.

NOTE 2 For UHV AC systems, the time to peak of switching overvoltage can be much higher than 250 us of the standard switching impulse time to peak, and depend on the UHV system conditions such as transmission line lengths and type of the circuit-breaker, etc. The withstand voltage of clearance to switching impulse with longer time to peak is greater than that to standard switching waveform. Air clearance test curves of switching impulse voltage with longer time to peak can be used for insulation coordination of transmission lines.

NOTE 3 Annex D shows diagrams of 50 % switching impulse withstand voltage over air clearance for typical setups of supports.

A typical example formula of lightning overvoltage is given below:

$$U_{50\%} \geq K_s K_a K_c U_{90\%\_ff} / (1 - 1{,}28\sigma) \quad \text{(B.4)}$$

where

$U_{90\,\%\_ff}$ is the the 90 % lightning withstand voltage of the insulator strings installed on the line;

K_s is the safety factor, 1;

K_c is the coordination factor, 1;

K_a is the altitude correction factor;

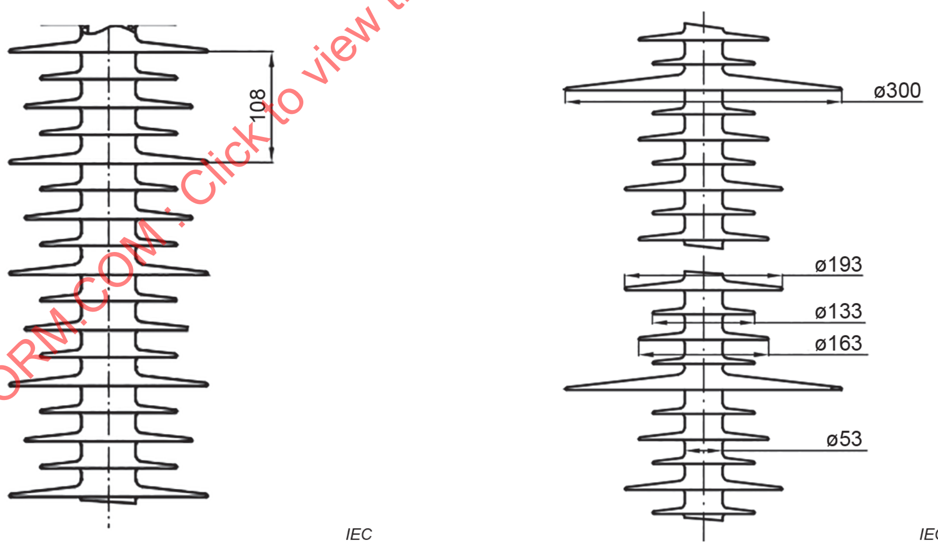
σ is the deviation factor, 0,03.

B.2.4 Insulation coordination

According to the latest pollution map and on-site pollution survey results of the State Grid Corporation of China, combined with operational experience and pollution characteristics, the project is divided into class c, class d, and class e pollution areas.

In principle, as for light ice zone and medium ice zone area, suspension string adopts composite insulator, and the tension string adopts porcelain or glass disc type insulator.

Referring to the previous UHV line engineering design experience and the research results of China Electric Power Research Institute, it is recommended to use composite insulators (structure height 9 m) for the 10 mm light ice area suspension string, and anti-icing composite insulators (structure height 9,75 m and larger diameter of umbrella skirt) for the 15 mm medium ice area suspension string. Typical figure of normal and anti-icing composite insulator profiles is shown below. Typical figure of normal and anti-icing composite insulator profiles is shown in Figure B.1 a) and b).



a) normal composite insulator profile

b) anti-icing composite insulator profile

Figure B.1 – Composite insulator profiles

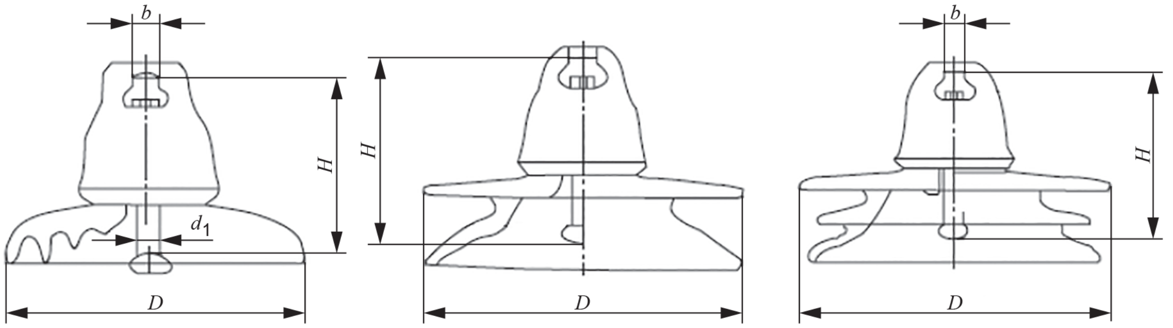
Tension insulator string configuration is shown as below. See Figure B.2 for 1 200 kV insulator profile. See Table B.4 and Table B.5 for configuration of tension insulator string in light and medium ice zone, and in substation outlet span respectively.

Table B.4 – Recommended configuration of tension insulator string in light and medium ice zone

Pollution Class	Insulator profile	Altitude			
		500 m [piece]	1 000 m [piece]	1 500 m [piece]	2 000 m [piece]
c(0,05 mg/cm^2 ~ 0,1 mg/cm^2)	420 kN two-alternating type U420BV	49	51	53	55
	420 kN standard type U420B	52	54	57	60
	550 kN three-alternating type U550BT	39	41	43	45
	550 kN standard type U550B 550 kN standard type U550B	45	47	49	51
d(0,1 mg/cm^2 ~ 0,25 mg/cm^2)	420 kN two-alternating type U420BV	58	60	62	64
	420 kN standard type U420B	69	72	75	78
	550 kN three-alternating type U550BT	48	50	52	54
	550 kN standard type U550B 550 kN standard type U550B	56	59	62	65
e(＞0,25 mg/cm^2)	420 kN two-alternating type U420BV	63	66	68	70
	20 kN standard type U420B	75	79	83	87
	550 kN three-alternating type U550BT	57	59	61	63
	550 kN standard type U550B 550 kN standard type U550B	62	65	68	71

Table B.5 – Recommended configuration of tension insulator string in substation outlet span

Pollution class	Insulator profile	Altitude			
		500 m [piece]	1 000 m [piece]	1 500 m [piece]	2 000 m [piece]
c(0,05 mg/cm^2 ~ 0,1 mg/cm^2)	300 kN two-alternating type U300BV 300 kN three-alternating type U300BT	56	59	61	63
d(0,1 mg/cm^2 ~ 0,25 mg/cm^2)	300 kN two-alternating type U300BV 300 kN three-alternating type U300BT	71	74	77	80
e(＞0,25 mg/cm^2)	300 kN two-alternating type U300BV 300 kN three-alternating type U300BT	78	81	84	87



Standard type | Two-alternating type | Three-alternating type

Figure B.2 – 1 200 kV insulator profile

The air gap of this project is taken as follows according to the table, and the value of the operating overvoltage gap is temporarily considered in accordance with 1,7 p.u. See Table B.6 and Table B.7 for value of single and double circuit line air gap respectively.

Table B.6 – Recommended value of single circuit line air gap

Altitude H (m)		500	1 000	1 500	2 000
Power frequency voltage gap d (m)		2,7	2,9	3,1	3,3
Switching overvoltage gap d (m)	(Side phase I string)	5,6	6	6,4	6,8
	(Medium phase V string)	6,7/7,9	7,2/8,0	7,7/8,1	8,2/8,3
Lightning overvoltage gap d (m)		not specified			
Live working clearance (m)	I string	5,6	6	6,4	6,9
	V string	6,2	6,7	7,2	7,9

NOTE 1 The gap value "/" value indicates the minimum gap value for the side of the tower window and the upper cross arm.

Table B.7 – Recommended value of double circuit line air gap

Altitude H (m)		500	1 000	1 500
Power frequency voltage gap d (m)		2,7	2,9	3,1
Switching overvoltage gap d (m)		6	6,2	6,4
Lightning overvoltage gap d (m)		6,7	7,1	7,6
Live working clearance (m)	Tower body	5,5	5,8	6,1
	Lower crossarm	5,7	6	6,3
	Top architecture	6,8	7,1	7,4

,

NOTE 2 The values in the table are I string data.

The main configuration of suspension string is as shown below:

– 3 “I” type strings for double circuit tower
– "I-V-I" type strings for single circuit tower
– 3”L” type strings for single circuit suspension angle tower.

The strength of main insulator string types is 300 kN, 420 kN and 550 kN.

The spacing distance between the suspension insulator strings is 600 mm.

The jumper insulator string on tension tower adopts squirrel cage rigid jumper equipment with 210 kN insulators.

B.2.5 Tower and foundation

a) Tower

- For single-circuit transmission lines, the horizontal conductor arrangement are adopted for suspension towers, and triangular arrangement for strain towers.
- For double-circuit transmission lines, the vertical conductor arrangement are adopted for suspension towers and strain towers.
- Equal angle steels are used for towers of single circuit transmission lines.
- The grade of steel material can be Q235, Q355 and Q420, and the largest member is L250x35.

NOTE 1 The grade of Q235, Q355 and Q420 means the minimum yield strength is 235, 355 and 420 MPa. For ASTM A36, the minimum yield strength is 250 MPa, and for ASTM A572, the grade of 42 and 50 means the minimum yield strength is 290 and 345 MPa. The grade of S235, S275 and S355 means the minimum yield strength is 235, 275 and 355 MPa in EN 10025.

- Steel tubes are used for double circuit transmission lines, and the grade of steel material can be Q235 and Q345.
- The bolts of 6,8 and 8,8 grade are adopted in transmission lines.
- All components of towers should adopt hot dip galvanized processing.

b) Tower load

The design of supports consider the following load cases: intact cases (weather loads), broken wire cases, construction and maintenance cases.

For intact cases, the supports may satisfy the following weather loads during normal operation.

- The basic wind speed, with no ice, no unbalanced longitudinal loads from conductors and ground wires;
- The design ice thickness, with concurrent wind speed and temperature, and without unbalanced longitudinal loads of conductors and ground wires;
- The load cases under the minimum temperature.

For broken wire cases, within the same span of double-circuit supports, unbalanced longitudinal loads can be applied to any two conductor phases, or any one conductor phase and any one ground wire.

For construction and maintenance cases, the construction loads can be calculated based on the meteorological conditions of no icing, concurrent wind speed and air temperature. The loads mainly refer to the actions of installing conductors, ground wires, insulators and hardware on supports.

Calculation of wind loads

- Wind loads include those applied on the conductors, ground wires, insulator strings and support itself, the wind loads can be calculated as follows:

$$F = \gamma_W \cdot \mu_Z \cdot \mu_S \cdot \beta_Z \cdot B \cdot W_0 \cdot A \quad \text{(B.5)}$$

where

F is the wind force in the direction of wind;

γ_w is the load factor based on the desired return period, for 1 000 kV, $\gamma_w = 1{,}1$;

μ_z is the height variation factor of wind pressure, for various heights above ground and for different exposure category, μ_z is calculated as follows:

$$\mu_z^A = 1{,}379 \cdot \left(\frac{Z}{10}\right)^{0{,}24} \qquad \text{(B.6)}$$

$$\mu_z^B = 1{,}000 \cdot \left(\frac{Z}{10}\right)^{0{,}32} \qquad \text{(B.7)}$$

$$\mu_z^C = 0{,}616 \cdot \left(\frac{Z}{10}\right)^{0{,}44} \qquad \text{(B.8)}$$

$$\mu_z^D = 0{,}318 \cdot \left(\frac{Z}{10}\right)^{0{,}60} \qquad \text{(B.9)}$$

μ_S is the force coefficient. For conductors and ground wires, μ_s = 1. μ_S = 1. For supports, the force coefficient can be determined taking into account the difference between the windward and leeward faces and the ratio of the actual area to profile area of the member concerned;

β_Z is the gust response factor for conductors, ground wires, and structures; when air flows, it presents the random fluctuating characteristics due to the effects of roughness of ground surface; therefore, wind loads do not only include static components of mean wind speed, but also fluctuating components with dynamic performance. The dynamic response of the structure should be considered with the gust response factor;

B is the load increase coefficient after icing, when design ice thickness is 10 mm, B = 1,2;

A is the area projected on a plane normal to the wind direction;

W_0 is the basic wind pressure, and should be calculated as follows:

$$W_0 = \frac{V^2}{1\,600}, \qquad \text{(B.10)}$$

where

V is the basic wind speed.

c) Foundation

– The types of foundations shall be selected comprehensively considering topography, geology, hydrology at the tower positions, and reaction of foundations.

– In cover shallow layer of rock subgrade, the rock foundations should be used, and the drilled foundations should be used in other mountainous and hilly regions.

– The drilled foundations should be preferred in plain regions with no groundwater, and the pad and chimney foundations should be adopted in other plain regions.

– The pile foundations should be used in soft ground areas.

– The concrete grade for rock foundations and pile foundations should be C30, and for other foundation types should be C25.

– The reinforcing steel bars should adopt HRB400 and HPB300.

– The connection of tower and foundation should adopt studs or anchor bolts.

– As for adverse geological process, such as liquefaction, corrosion, mining influence area, collapsible loess etc., the reasonable treatments for foundation design should be applied.

NOTE 2 HRB400 and HPB300 are Chinese standard. HRB400 means Hot rolled Ribbed Bars, and its yield strength is 400 MPa. HPB300 means Hot rolled Plain Bars, and its yield strength is 300 MPa.

B.3 Design practice in India

B.3.1 General

Indian Power System has grown rapidly in the past two to three decades. Installed generation capacity has already surpassed 350 GW and a gigantic network of more than 400,000 circuit km of 220 kV and above voltage level transmission lines traverses through the entire length and width. Being a country with high population density, the environmental concerns and right of way constraints have increased substantially with the growth of the transmission network. In order to minimise the land use and per MW right of way requirements, bulk power transmission systems at EHV and UHV levels have been planned in the country. At present there are numerous 765 kV double circuit AC lines and three +/-800 kV UHVDC bipole transmission lines in service. India has also established 1 200 kV National Test Station at Bina, Madhya Pradesh comprising of one 1 200 kV single circuit test line and one 1 200 kV double circuit test line. Also, one 400 kV double circuit (upgradable to 1 200 kV UHVAC single circuit) Wardha-Aurangabad transmission line is presently under construction.

B.3.2 Challenges in development and solutions

The need for development of next high level transmission network i.e. 1 200 kV UHVAC network was felt few years ago keeping in view the future power scenario. Being one of the highest voltage level in the world, not much experience was available. Accordingly, detailed studies for design and optimization of 1 200 kV transmission line were taken up. The studies were further supplemented with full scale testing for verifying corona aspects and optimizing electrical clearance requirements. Before taking up construction of a commercially operated 1 200 kV transmission line, it was considered appropriate to set up a 1 200 kV test line and station. It was also decided to implement one of the planned 400 kV double circuit line between two major pooling stations as a 1 200 kV upgradable line for conserving right of way for future sustainable growth.

Detailed studies were carried out in respect of conductor-bundle selection, tower design optimization, electrical clearances, insulator selection, earth wire selection etc. for the 1 200 kV transmission line.

B.3.3 Conductor selection

Octagonal Moose conductor bundle has been selected for 1 200 kV single circuit transmission line based on detailed conductor bundle selection studies comprising of following aspects:

Initially following four alternative conductor bundle configurations were identified for detailed studies:

– hexagonal ACSR Lapwing;
– octagonal ACSR Moose;
– octagonal ACSR Bersimis;
– octagonal ACSR Lapwing.

a) Thermal Capacity of bundle configurations: Based on ambient temperature of 45° as well as other conductor and environmental parameters, following current carrying capacity at maximum operating temperature for ACSR conductors have been calculated. See Table B.8.

Table B.8 – Conductor capacity

No.	Conductor bundle	Ampacity/ subconductor at 85°C (A)	Thermal capacity of 1 200 kV single circuit line (MVA)
1	Hexagonalgonal ACSR Lapwing	1 006	12 022
2	Octagonal ACSR Moose	787	12 540
3	Octagonal ACSR Bersimis	912	14 532
4	Octagonal ACSR Lapwing	1 006	16 030

b) Interference studies

Each conductor bundle has been analysed based on following interference studies:

i) Surface gradient: the following results have been obtained for conductor surface gradient and corona onset gradient. See Table B.9.

Table B.9 – Conductor surface gradient

No.	Conductor bundle	Conductor surface gradient (kV/cm), max.	Corona onset gradient (kV/cm)
1	Hexagonal Lapwing	16,9	19,62
2	Octagonal Moose	16,1	19,97
3	Octagonal Bersimis	14,8	19,78
4	Octagonal Lapwing	13,8	19,62

Conductor surface gradients for above conductor bundle alternatives are within acceptable limits

ii) Radio interference: the following results have been obtained for radio interference at the edge of right of way. See Table B.10.

Table B.10 – Conductor radio interference

No.	Conductor bundle	Radio Interference (dB/µV/m)
1	Hexagonal Lapwing	35,3
2	Octagonal Moose	28,7
3	Octagonal Bersimis	26,3
4	Octagonal Lapwing	24,7

RI levels for above conductor bundle alternatives are within acceptable limits

iii) Audible noise: the following results have been obtained for audible noise at the edge of right of way. See Table B.11.

Table B.11 – Conductor audible noise

No.	Conductor bundle	Audible Noise (dB(A))- L5 level	Audible Noise (dB(A))- L50 level
1	Hexagonal Lapwing	60,2	57,3
2	Octagonal Moose	56,8	52,2
3	Octagonal Bersimis	55,5	50,2
4	Octagonal Lapwing	54,4	48,4

iv) Electric field: the following results have been obtained for electric field (see Table B.12):

Table B.12 – Conductor electric field

No.	Conductor bundle	Electric field (max.) (kV/m)	Electric field at edge of right of way (kV/m)
1	Hexagonal Lapwing	9,8	3,7
2	Octagonal Moose	9,8	4,0
3	Octagonal Bersimis	9,9	4,1
4	Octagonal Lapwing	9,9	4,1

Based on the above studies, Octagonal Moose, Octagonal Bersimis and Octagonal Lapwing were found to meet the interference criteria. Keeping in view that the line shall be initially operated as 400 kV double circuit with Quadruple Moose configuration and the same conductor can be utilized for upgrading to 1 200 kV Octagonal configuration, Octagonal Moose has been selected as the optimal conductor bundle for 1 200 kV line.

B.3.4 Electrical clearances

a) Air gap clearances

The air gap clearance under various insulator swing angles for "I" string insulator configuration has been calculated based on following criteria:-

i) Swing angle under wind velocity corresponding to a 50-year return period combined with distance necessary to withstand power frequency over voltage. This corresponds to a clearance of 2,4 m at 41-degree swing angle;

ii) Swing angle having a probability of occurrence of 1 % or more during a year (or the swing angle under wind velocity corresponding to 12,5 year return period) combined with distance necessary to withstand switching over voltage. This corresponds to a clearance of 8 m at 10-degree swing angle;

iii) Swing angle under stationary wind conditions combined with distance necessary to withstand switching over voltage. This corresponds to a clearance of 8 m at 0 degree swing angle.

In case of V string insulator configuration, keeping in view no swing, clearance requirement is only at stationary position. As such, minimum clearance from V string shall be 8 m.

Electrical clearances adopted for 1 200 kV line have been finalized based on full-scale experimental tests conducted at Central Power Research Institute (CPRI), India. See Table B.13 for salient results of the experimental tests.

Figure B.3 – 1 200 kV air-gap experimental tests

Table B.13 – Salient results of the experimental tests

No.	Gap distance (m)	Crest time (Tp) (μs)	50 % flashover voltage $U_{50\ \%}$ (kV_p)	50 % flashover voltage after atm. correction $U_{50\ \%}$ (kV_p)
1	8	160	1 926	1 951
		250	1 879	1 915
		270	1 868	1 906
		350	1 854	1 910
2	8,5	115	2 191	2 236
		250	1 950	1 963
		270	1 937	1 953
		350	1 948	1 961

b) Ground Clearance

Minimum ground clearance of 24 m is arrived for Octagonal Moose conductor bundle configuration so as to limit the maximum electric field within ROW to 10 kV/m at 1,8 m above ground level.

c) Conductor to earth wire Separation: Following criteria has been followed for earth wire selection and conductor to earth wire separation for 1 200 kV:

– Average surface gradient on earth wire due to line voltage shall not exceed 90 % of their corona onset gradient under fair weather conditions.

– Minimum air gap distance required for switching over voltage should exist between conductor and earth wire under swing conditions.

– Total flashovers due to shielding failures and backflashovers shall not exceed 0,1 per 100 km per year.

– Maximum shielding angle of 10 degrees.

Based on the above, min. earth wire diameter of 15 mm with conductor to earth wire separation of 18 m has been fixed. The earth wire configuration shall be 19/3,0 mm.

d) Right of way requirements: In addition to the interference criteria, right of way in India is also calculated on the basis of country regulations. Based on the stipulated horizontal clearance of 13 m for 1 200 kV, the ROW for various insulator string configuration works out to as follows.

– horizontal tower with IVI configuration - 106 m;

– horizontal tower with VVV configuration - 92 m.

See Figure B.3 for 1 200 kV air-gap experimental tests.

Keeping in view that ROW requirement of VVV configuration is lower and the calculated tower weights for this tower are also lower than that with IVI configuration, the horizontal tower with VVV configuration has been selected for 1 200 kV single circuit line in India.

B.3.5 Insulation requirements

a) Pollution withstand: based on specific creepage distance of 25 mm/kV for heavy pollution level, total creepage requirement shall be 30 000 mm. In view of available creepage distance of 590 mm per disc insulator, the minimum numbers of insulators work out to 51 numbers.

b) Switching overvoltage withstand: with the total 51 numbers of insulators of 195 mm height, the air gap clearance requirement for switching overvoltage withstand of 1 800 kVp (viz. 8 m) is also met.

c) EandM rating of insulators are decided based on following criteria:

Suspension String

– Mechanical loading under no wind conditions not to exceed 25 % of EandM rating of insulators.

– Mechanical loading under full wind conditions not to exceed 70 % of EandM rating of insulators.

Tension String

– The rating of insulator string shall not be less than that of conductor bundle.

– Accordingly, 2 × 320 kN V insulator string for suspension towers and 4 × 320 kN insulator string for tension towers have been finalized.

B.3.6 1 200 kV test line

One 1 200 kV single circuit test line and one 1 200 kV double circuit test line have been constructed in the 1 200 kV test station at Bina, Madhya Pradesh, India with collaborative efforts of Power Grid Corporation of India Ltd., Central Power Research Institute, Central Electricity Authority and domestic manufacturers of the country. A 1 200 kV single circuit test line consists of an octagonal Moose conductor configuration on horizontal configuration as well as vertical delta configuration towers. A 1 200 kV double circuit test line consists of an octagonal Bersimis conductor configuration on vertical configuration towers. Corona performance of these test lines has been good and electric fields measurements are found to be within acceptable limits. See Table B.14 for salient features of the 1 200 kV test lines. See Figure B.4 and Figure B.5 for 1 200 kV single and double circuit test line respectively.

IEC

Figure B.4 – 1 200 kV single circuit test line

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Figure B.5 – 1 200 kV double circuit test line

Table B.14 – Salient features of the 1 200 kV test lines

	1 200 kV D/C line	**1 200 kV S/C line**
Height of Towers	125 m	55 m
Conductor	Octa-Bersimis	Octa-Moose
Basic Span	400 m	400 m
Wind Zone	2 (39 m/s)	2 (39 m/s)
No. of Towers	Suspension: 1 no. Dead end: 2 nos.	Suspension: 3 nos. Dead end: 2 nos.
Ground clearance	30 m	24 m
Mid span clearance	16 m	18 m
Phase-to-phase clearance	25 m	24 m

B.3.7 400 kV double circuit (upgradable to 1 200 kV single circuit) line

The upgradable 400 kV double circuit (quadruple bundle) Wardha-Aurangabad transmission line has been designed and is being constructed such that the same may be upgraded/ converted to 1 200 kV single circuit transmission line at a later date as per requirement.

Following six types of Horizontal configuration towers have been fixed: A type (0 deg suspension tower), AS type (7-degree suspension tower), B type (15-degree tension tower), C type (30-degree tension tower), D type (45-degree tension tower), DE type (60-degree tension tower).

The designs of the towers for the upgradable line have been developed in such a way that all electrical clearance requirements with respect to 1 200 kV as well as two horizontal circuits of 400 kV quadruple bundle line are met. Indicative sketches/Single line diagrams of suspension and tension towers of the 1 200 kV upgradable transmission line are shown below. See Figure B.6 and Figure B.7 for Indicative sketches/Single line diagrams of suspension and tension towers of the 1 200 kV upgradable transmission line respectively.

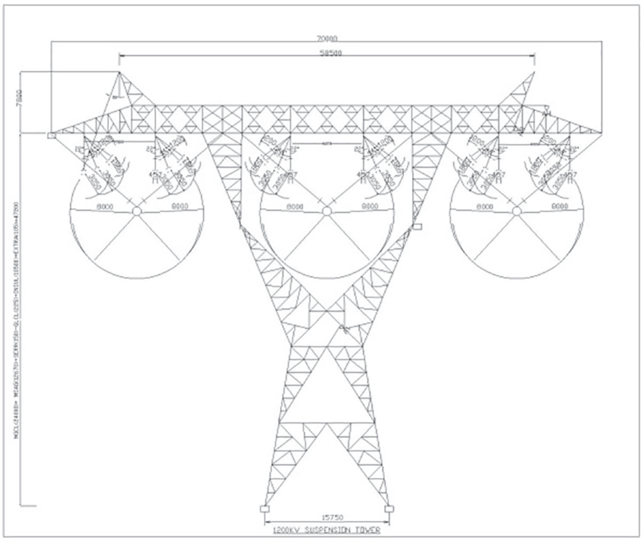

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Figure B.6 – 1 200 kV upgradable line –Suspension tower

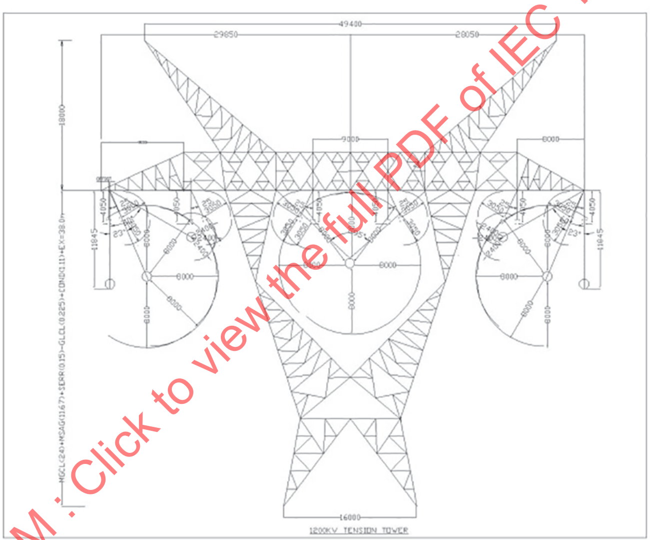

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Figure B.7 – 1 200 kV upgradable line –Tension tower

Towers have been designed considering reliability level-2 (150 year return period).

Full scale prototype testing of all type of towers was done to verify the designs prior to taking up manufacturing and construction of the transmission line. See Figure B.8 for 1 200 kV Tower Prototype Testing.

IEC

Figure B.8 – 1 200 kV Tower Prototype Testing

Salient technical parameters and features of the 1 200 kV upgradable line are summarized below (see Table B.15):

Table B.15 – Salient features of 1 200 kV upgraded transmission line

Salient Features	400 kV double circuit (quadruple bundle) line (being constructed)	1 200 kV single circuit line (after upgradation in future)
Conductor-bundle	Quadruple ACSR Moose (54/3,53 mm+7/3,53 mm) – 2 Ckts	Octagonal ACSR Moose – 1 Ckt (same conductors to be used)
Number and size of earth wire	2,19/3,0 mm GS (same earth wires to be used)	
Type of towers	Suspension type (A, AS) and Tension type (B, C, D and E) (same towers to be used)	
Live-metal/air gap clearance	3,05 m for 400 kV and 8,0 m for 1 200 kV (towers designed to meet 400 kV and 1 200 kV clearances)	
Ground clearance	24 m (ground clearance corresponding to 1 200 kV considered)	
Insulator strings	Double suspension, 120 kN (2 x 23) and quadruple tension, 160 kN (4 x 23) for 400 kV	Single V Suspension, 320 kN (2 x 51) and quadruple tension, 320 kN (4 x 51) (new insulator strings to be used for upgraded line)

B.4 Design practice in Japan

B.4.1 General

In Japan, four UHV AC transmission lines were constructed in 1990's. They are designed to withstand 1 100 kV and are currently operating at 550 kV.

The design practice of UHV AC transmission line in Japan is as follows (see Table B.16):

Table B.16 – UHV AC transmission lines in Japan

T/L	length [km]	number of towers	year of operation start
Nishi-Gunma Trunk Line	138	217	1992
Minami-Niigata Trunk Line	50	86	1993
Kita-Tochigi Trunk Line	109	165	1996
Minami-Iwaki Trunk Line	130	235	1999

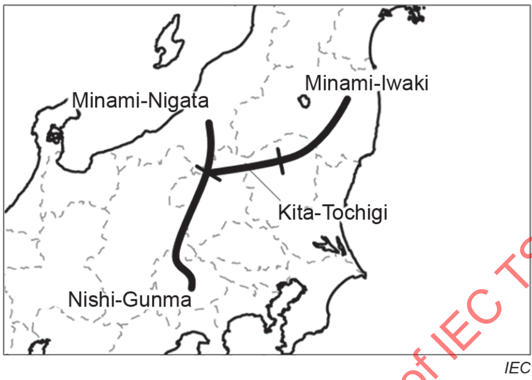


Figure B.9 – UHV AC transmission lines in Japan

B.4.2 Conductor and earth wire

a) Conductor selection

Four types and six cases shown in Table B.18 are compared, and 610 mm^2 × 8 (sub-conductor spacing of 40 cm) at which AN (Audible Noise) is 50 dB(A) or less is selected as a basic conductor configuration.

For places where residences exist within 300 m of transmission line, 810 mm^2 × 8 is selected at which AN is 50 dB(A) or less even if wind noise mitigation measure (spiral rod) is installed to conductor. See Figure B.10 for 610 mm^2 conductor configuration.

For Kita-Tochigi Trunk Line and Minami-Iwaki Trunk Line, since the route is frequently close to residences, the newly developed low-noise type 960 mm^2 × 8 and low-noise type 940 mm^2 × 8 are adopted instead of 810 mm^2 × 8 with wind noise mitigation measure. This conductor suppresses wind noise by making outer layer strands into a special shape, and also suppresses AN. See Table B.17.

See Figure B.10 for 810 mm^2 conductor configuration.

Table B.17 – Conductor configuration and AN

conductor configuration	wind noise mitigation measure	AN [dB(A)]	remark
810 mm^2 × 8	not installed	45	
	installed	49	adopted
610 mm^2 × 8	not installed	50	adopted
	installed	54	
810 mm^2 × 8	not installed	60	
410 mm^2 × 8	not installed	53	

Dimensions in millimetres

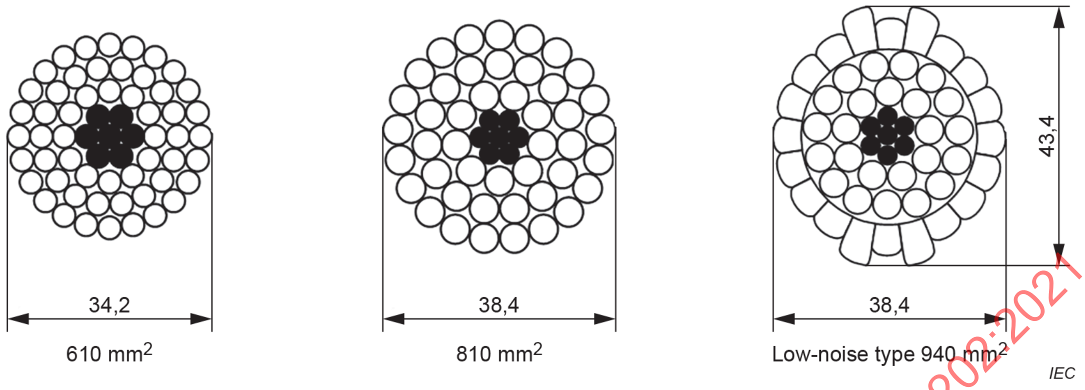


Figure B.10 – Shape of conductor

b) Earth wire selection

OPGW 500 mm² is selected as a basic earth wire. This is newly developed based on the requirements shown in Clause G.4.

For places where residences exist within 300 m of transmission line, the facility is designed that wind noise mitigation measure (spiral rod) can be installed to OPGW 500 mm². See Figure B.10 for 940 mm² conductor configuration.

For Minami-Iwaki Trunk Line, since the route is frequently close to residences, the newly developed low-noise type OPGW 480 mm² are adopted instead of OPGW 500 mm² with wind noise mitigation measure. This earth wire has some thickened outer layer strands to suppress wind noise. See Figure B.11 for 500 mm² and 480 mm² OPGW configuration.

Dimensions in millimetres

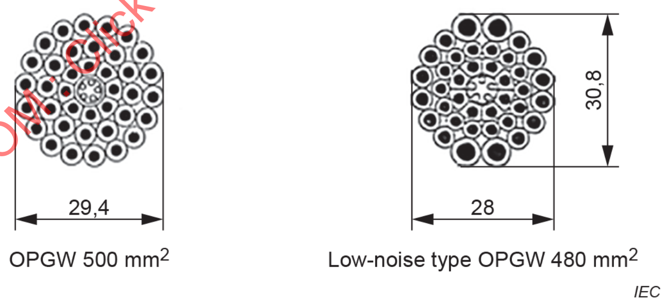


Figure B.11 – Shape of OPGW

c) Anti-vibration measure for conductor and earth wire

Distributed damper are adopted for earth wire. See Clause E.4 for details.

B.4.3 Insulation coordination

a) Insulator design

For UHV AC transmission line in Japan, porcelain insulator of suspension type and anti-pollution suspension type are adopted.

Several diameter are prepared for each insulator, and they are used to shorten the length of insulator string while taking into consideration air gaps and construction costs.

Table B.18 – Specifications of insulator

type	suspension type			anti-pollution suspension type	
diameter	320 mm	340 mm	380 mm	400 mm	420 mm
coupling length	195 mm	205 mm	240 mm	195 mm	205 mm
strength	330 kN	420 kN	530 kN	330 kN	420 kN

The target withstand voltage under pollution or snow is calculated using the following formulas:

$$\text{power frequency: } U_\text{m} / \sqrt{3} \cdot K_\text{sg} \tag{B.11}$$

$$\text{switching surge: } \sqrt{2} \cdot U_\text{m} / \sqrt{3} \cdot n \tag{B.12}$$

where

U_m is the maximum voltage: 1 100 [kV];

K_sg is the sound phase voltage factor at single phase ground fault = 1,10 to 1,20;

n is the switching surge factor: 1,6 p.u. to 1,7 p.u.

The withstand voltage of single insulator under pollution or snow is shown as Table B.19, Table B.20. For Minami-Niigata Trunk Line, since the route passes through heavy snow areas, the drop of withstand voltage under snow is also taken into consideration.

The region of pollution and snow is determined by comprehensively judging the field observation, the distance from the coast, the topography and so on.

Table B.19 – Withstand voltage of single insulator in pollution [kV/unit]

	region	ESDD	suspension type			anti-pollution suspension type	
			320 mm	340 mm	380 mm	400 mm	420 mm
power frequency withstand voltage	A	0,011 mg/cm^2	19,5	20,5	24,0		
	B	0,03 mg/cm^2	15,0	15,8	18,5	18,5	18,8
	C	0,06 mg/cm^2	12,8	13,6	15,7	15,9	16,2
switching surge withstand voltage	A	0,011 mg/cm^2	52,4	55,1	64,5		
	B	0,03 mg/cm^2	40,3	42,4	49,7		
	C	0,06 mg/cm^2	34,4	36,5	42,2		

Table B.20 – Withstand voltage of single insulator under snow [kV/unit]

	region	snow conductivity	suspension type	
			340 mm	380 mm
power frequency withstand voltage	I	100 µS/cm	14,5	17,0
	II	50 µS/cm	16,0	18,8
switching surge withstand voltage	I	100 µS/cm	27,2	31,9
	II	50 µS/cm	31,1	36,4

b) Air gap

50 % flashover withstand voltage (U_{50}) for power frequency or for switching surge is calculated using following formulas:

power frequency: $$U_{50} = U_{\mathrm{m}} / \sqrt{3} \cdot \mathrm{K}_1 \cdot \mathrm{K}_2 \text{ [kV]} \tag{B.13}$$

switching surge: $$U_{50} = \sqrt{2} \cdot U_{\mathrm{m}} / \sqrt{3} \cdot n \cdot \mathrm{K}_1 \cdot \mathrm{K}_2 \text{ [kV]} \tag{B.14}$$

where

U_{m} is the maximum voltage = 1 100 [kV];

n is the switching surge factor = 1,6 p.u. to 1,7 p.u.;

K_1 is the altitude correction factor, see Table B.21;

K_2 is the withstand voltage factor = 1/0,91 (power frequency), 1/0,85 (switching surge).

Air gap (d_{air}) for power frequency or for switching surge is calculated using following empirical formulas:

power frequency: $$d_{\mathrm{air}} = (e^{\sqrt{2} \cdot U_{50}/1\,080/k} - 1)/0{,}46 \tag{B.15}$$

switching surge: $$d_{\mathrm{air}} = (e^{U_{50}/1080/k} - 1)/0{,}46 \tag{B.16}$$

where

U_{50} is the 50 % flashover withstand voltage [kV];

k is the gap coefficient = 1,35 (power frequency), 1,19 to 1,41 (switching surge).

Table B.21 – Altitude correction factor K_1

altitude (H)	H ≤ 800 m	800 < H ≤ 1 800 m	1 800 m < H ≤ 2 100 m
power frequency	1,12	1,22	1,25
switching surge	1,05	1,10	1,11

The horn spacing is set as 6,3 m for suspension tower or 5,9 m for tension tower. It is determined under the condition that the horn spacing is larger than the length of insulator string×0,85 (horn spacing efficiency) calculated from the pollution withstand voltage for power frequency, air gap for switching surge, and the height of tower or the width of conductors is not excessively enlarged. The lightning flashover rate assumed by this horn interval is 0,28 times to 0,48 times/100 km/year.

The standard insulation gap is set to the horn spacing × 1,1 to fix the flashover path between the horns.

B.4.4 Wind noise

a) Characteristics of wind noise

– Wind noise from conductors

When a uniform wind is applied from the direction perpendicular to the conductor, Karman vortices appear and disappear periodically in the lee side of the conductor. This generates pressure fluctuation in the air causing audible sound with a dominant frequency. In case of a turbulent wind, the wind noise has no dominant frequency, so that it is less likely to cause complaints.

The dominant frequency is proportional to 1/d and U, where "d" is the diameter of the conductor, "U" is the wind velocity. It is a low frequency of 50 Hz to 200 Hz for the ordinary conductor and the strong wind that occur frequently.

The directivity of wind noise is perpendicular to the conductor and the wind. The wind generally blows horizontally; the loudest wind noise is heard beneath the transmission line.

The noise level is proportional to U6 for the wind velocity "U". The UHV AC transmission line is vulnerable to this effect because the wind velocity increases as the height of the conductor increases.

When two conductors are arranged horizontally, the wake of the upwind conductor interferes with the Karman vortex of the downwind conductor causing louder noise. This phenomenon becomes remarkable when the spacing between the conductors is 5 to 10 times the diameter of conductor. In this condition, the noise level of double conductors arranged horizontally becomes about 8 times as large as that of a single conductor. On the other hand, the noise level of double conductors arranged vertically is simply twice that of a single conductor. The UHV AC transmission lines using multiple conductors are facilities that generate loud noise in this regard.

– Wind noise from insulators

When an insulator with pleats is exposed to wind from a particular direction, a periodical flow is formed within the pleats. If it coincides with the natural period of the insulator string at a specific wind velocity, it sounds as a large resonance sound. It has a dominant frequency of several hundreds Hz and is a characteristic tone often likened to a whistling sound. The event probability is low, and the noise occurs intermittently, because it is not generated unless the conditions of wind direction and wind velocity are matched.

The wind direction of about 65 degrees to 85 degrees to the axis of the insulator string is in condition that the noise may occur. In order to satisfy this condition, a suspension insulator device in which the insulator axis is oriented vertically requires a topographic feature that causes a slight upward wind, while a tension insulator device in which the insulator axis is oriented horizontally requires wind blowing from a specific direction (about only 1/4 of all wind directions meet the condition).

The condition of wind velocity that the noise may occur is depending on the type of insulator, and are discrete, for example, around 10 m/s, 15 to 18 m/s and 27 to 38 m/s. When the wind velocity is high, the dominant frequency is high, the noise level is high, and the condition of wind becomes wide.

b) Reference level of wind noise

The wind noise from both conductors and insulators have dominant frequency. When the wind noise exceeds the background noise + 10 dB(A) at the frequency, the psychological influence and the possibility of leading to complaints would increase, but it is recommended to determine the reference level by conducting experiments because the feeling differs depending on the person.

Since wind noise fluctuates irregularly, L_5, L_{50}, L_{eq}, L_{dn} are useful in order to examine the relationship between noise level and complaints as well as the corona noise. These values should be compared with the background noise + 10 dB(A). However, if the possibility is very low, such as the wind noise from insulators, it is difficult to predict whether the noise leads to complaints or not by this approach.

c) Prediction of wind noise

– Wind noise from conductors

The characteristics of the wind noise with respect to the wind velocity, the diameter of the conductor, the conductor arrangement, the directivity and others should be obtained in advance through the existing transmission lines, test lines, and wind tunnel experiments.

The level and probability of the noise could be predicted from the characteristics and statistics of wind direction and wind velocity in the route.

– Wind noise from insulators

The characteristics of the wind noise with respect to the type of insulator, wind velocity, wind direction and others should be obtained in advance through existing transmission lines, test lines, and wind tunnel experiments.

The level and probability of the noise could be predicted from the characteristics and statistics of wind direction and wind velocity in the route.

d) Mitigation measures of wind noise

If complaints about wind noise are predicted or occur, the following measures should be taken appropriately to mitigate the wind noise.

– Wind noise from conductors

Install spiral rods to the conductors. The spiral rod make the surface of the conductors uneven, and suppress the Karman vortex in the lee side of the conductors.

The spiral rod mitigates wind noise but induces corona discharge of the conductor. In order to relieve this, a winding form such as two tight strips or four diagonal strips is adopted.

As a relaxation measure similar to the spiral rod, there is a low-noise conductor designed to suppress the Karman vortex and prevent corona discharge by changing the strand diameter or shape of the outer layer by several pieces.

– Wind noise from insulators

Attach vibration absorbers to the connecting part (pin and cap) of the insulator to suppress the resonance of the insulator string.

B.4.5 Tower and foundation

a) Tower

Comparing three cases (1 route of double circuits vertical arrangement self-supporting tower, 2 routes of single circuit horizontal arrangement self-supporting tower, 2 routes of horizontal arrangement single circuit guy-supporting tower), the first is judged to be economically advantageous and adopted.

The tower has two earth wires. They are arranged 2,5 m outside of conductors to make shielding angle negative.

Since loads for tower are large and members of tower are long, most of members, including arms, are steel pipes.

The materials of STK400 (tensile strength 400 N/mm^2) and STKT590 (tensile strength 590 N/mm^2) are used for steel pipes.

The grade of 5,8 (tensile strength 520 N/mm^2), 6,8 (tensile strength 500 N/mm^2), 9,8 (tensile strength 900 N/mm^2) are used for bolts.

b) Loads for tower design

The load of wind, ice accretion, snow accumulation have been determined by comprehensively judging public weather data, local weather observation data over several years. Two kinds of criteria have been adopted for wind loads: one is based on average wind speed and the other is based on gust wind speed. The detail of loads used for tower design is shown in Table B.22.

Table B.22 – Loads for tower design

Criteria	condition	Detail of loads	strength
Average wind speed method	high temperature season	wind pressure 880 Pa (conductor) 1 270 to 1 470 Pa (tower)	σ_a
	low temperature season	wind pressure 440 Pa (conductor) 635 Pa to 735 Pa (tower) ice accretion 6 mm to 9 mm, density = 0,9	σ_a
Gust wind speed method	strong wind	wind pressure 1 670 to 3 630 Pa (conductor) 2 750 to 6 080 Pa (tower)	σ_y
	snow	snow accretion 30 mm to 50 mm, density = 0,6 wind pressure 300 Pa to 440 Pa (conductor) 780 Pa to 1 320 Pa (tower)	σ_y
	ice	ice accretion 3 kg/m to 8 kg/m wind pressure 300 Pa to 490 Pa (conductor) 260 Pa to 300 Pa (tower)	σ_y
Snow accumulation	-	pressure of snow settling and moving with load of low temperature	σ_y

c) Foundation

Foundation of UHV AC transmission line is required to withstand large load, pile type foundation and caisson type foundation are mainly adopted. Pile type is applied to roughly plain location, and caisson type is applied to steep slope.

As for caisson type, anchor type and expanded base type are adopted, which can withstand large load while suppressing construction costs. See Figure B.12 for Pile and Caisson type foundation.

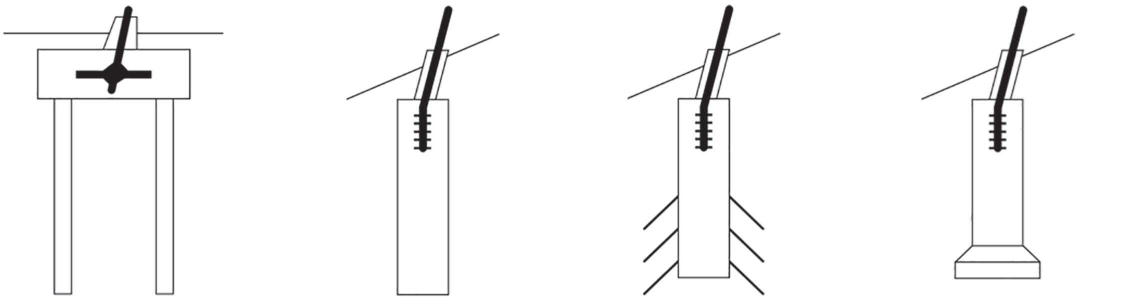


Figure B.12 – Foundation type

Annex C
(informative)

Construction practice of UHV AC transmission lines in different countries

C.1 General

Basic construction practice of UHV AC transmission lines in different countries are respectively given in Clause C.2 (China), Clause C.3 (India) and Clause C.4 (Japan).

C.2 Construction practice in China

The length of path of Yuheng-Weifang 1 000 kV AC transmission line is about 1 060 km, and the line route crossed Shaanxi, Shanxi, Hebei, and Shandong province. The line consists of two single-circuit line and double-circuit line.

a) Transportation and preparing work at site

The rail transport and motor transport are mainly adopted for material transport from manufacturers to material station, and to site, cableway may be used.

b) Foundation

Mechanized construction is adopted for foundation construction in the whole process. According to their characteristic of different foundation types, suitable machinery may be used, for example, anchor drilling rig (see Figure C.1 a) is used for rock anchor foundations, rotary drilling rig (see Figure C.1 b) is used for drilled foundations, and so on. For some site that vehicle cannot reach, pumping concrete or cableway may be used.

a) **Anchor drilling rig**

b) **Rotary drilling rig**

Figure C.1 – Machinery for foundation construction

c) Assembling of tower

Holding pole is widely used in assembling towers, the common holding pole has single holding pole, humanoid holding pole, holding pole with rotating arm, combined holding pole, and so on. In the plain area, crane may be used. Electric constant torque wrench can be used for bolt fastening.

d) Stringing

Unreeling and setting the leading string by the aid of dynamic parachute, unmanned aerial vehicle and airship. Then tractors, tensioners and other mechanical equipment can be used in the stringing of conductor and ground wire.

e) Quality control

To ensure the engineering quality, the model of the whole process of quality management is adopted. For example, In the material production process, mill supervision is used in factory, and in the construction site, uses the field supervising.

C.3 Construction practice in India

The transmission line towers are self-supporting lattice structures. Steel section of tested quality of grade E 250 (Designated Yield Strength 250 Mpa) and/or grade E 350 (Designated Yield Strength 350 MPa) are used in towers and extensions. Open cast foundations of following types are used for transmission lines in India:

i) Dry
ii) Wet
iii) Partially Submerged
iv) Fully Submerged
v) Wet Paddy
vi) Dry Fissured Rock
vii) Wet Fissured Rock
viii) Submerged Fissured Rock
ix) Wet Black Cotton
x) Sandy
xi) Hard Rock

Pile foundations are used for locations falling within the course of river which are likely to get scoured or at locations having soil of very poor bearing capacity.

The erection of towers is conventionally carried out using gin pole, derrick, centre mast, etc. through usage of power operated Winch machines. At some locations, cranes are also used for tower erection. The stringing of conductor is carried out by tension stringing technique using power operated winch machines. Ladders with suitable hooks are used to facilitate worker movement on insulator strings. Sagging bridges/working platform with pull lifts are used at crossarm level for facilitating sagging and dead-end jointing.

Helicopters can also be used for stringing of conductors and drones can be used for stringing of pilot wires or ropes for pilot wire.

C.4 Construction practice in Japan

For UHV AC transmission line in Japan, the following measures are adopted in order to efficiently construct large-scale equipment.

a) Transportation

Vehicles, cableways and helicopters of 3 t class are used for transportation of materials and equipment.

b) Foundation

The depth of caisson type foundation is several 10 m, excavation and soil removal work are mechanized.

c) Assembling of tower

Climbing crane of 36 t·m to 65 t·m class is used for assembling of tower. In accordance with the lifting capacity of the crane, limit weight of each member and arm block are set as 2,8 t.

d) Stringing

In order to minimize work on the tower, the prefabricated stringing method and the full prefabricated stringing method are adopted.

The prefabricated stringing method is in which marks are attached to calculated positions of the conductor in the factory, it is cut according with the marks and compression clamps are attached on the ground at the site, then stringing is carried out. The full prefabricated stringing method is in which clamps are attached to calculated positions of the conductor in the factory, then stringing is carried out immediately.

Annex D
(informative)

Flashover voltage test result for air clearances in different countries

D.1 General

Main flashover voltage test result of UHV AC transmission lines in different countries are respectively given in Clause D.2 (China), Clause D.3 (India) and Clause D.4 (Japan).

D.2 Flashover voltage test result for air clearances in China

D.2.1 50 % Power frequency flashover voltage test results for air clearances of transmission line structures

See Figures D.1 to D.10 for arrangement of power frequency flashover voltage test for single and double circuits lines.

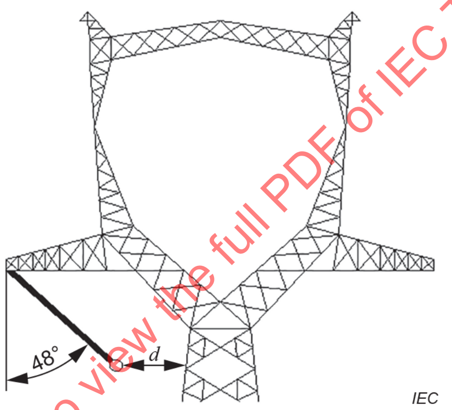


Figure D.1 – The arrangement of power frequency flashover voltage test for side-phase air clearances of 1 000 kV cat-head type towers

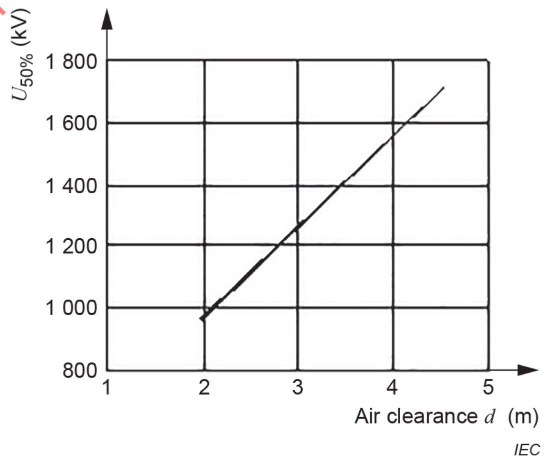


Figure D.2 – The 50 % power frequency flashover voltage characteristic for air clearance from side-phase conductor to tower body for 1 000 kV cat-head type towers

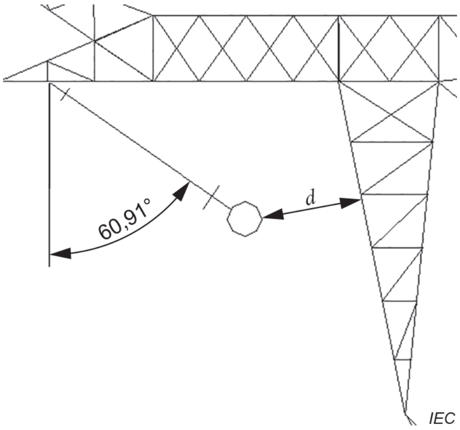


Figure D.3 – The arrangement of power frequency flashover voltage test for side-phase air clearances of 1 000 kV cup type towers

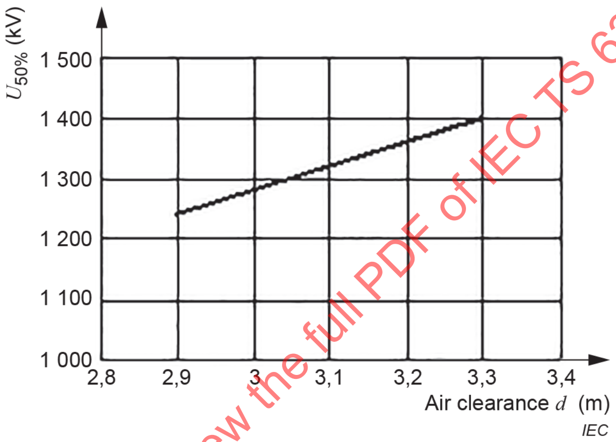


Figure D.4 – The 50 % power frequency flashover voltage characteristic for air clearance from side-phase conductor to tower body for 1 000 kV cup type towers 1 000 kV cup type towers

Dimensions in metres

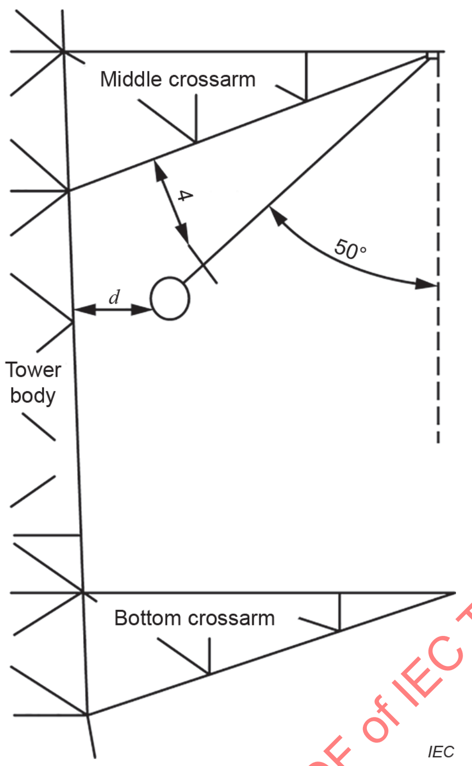


Figure D.5 – The arrangement of power frequency flashover voltage test for air clearances of 1 000 kV double-circuit lines

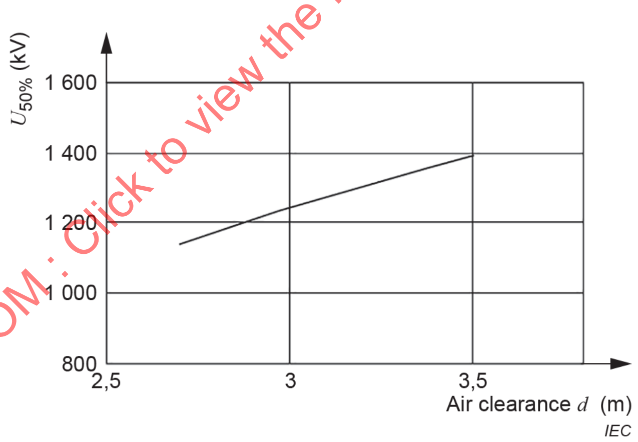


Figure D.6 – The 50 % power frequency flashover voltage characteristic for air clearance from middle-phase conductor with I-type string to tower body for 1 000 kV double-circuit lines

Dimensions in metres

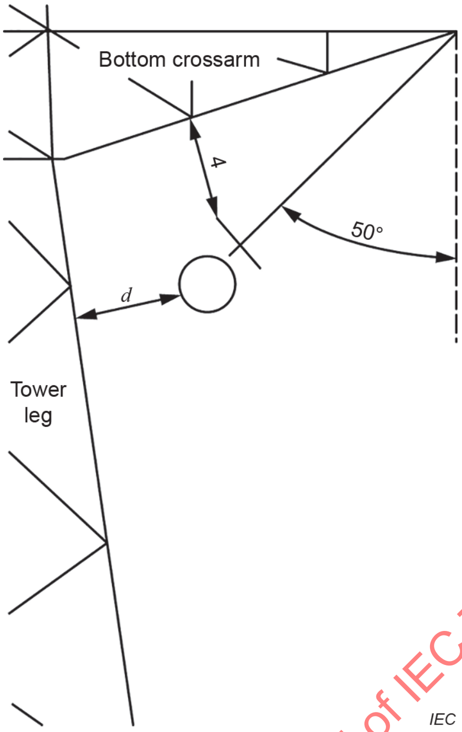


Figure D.7 – The arrangement of the power frequency flashover voltage test for air clearances of bottom-phase with I-type string of 1 000 kV double-circuit lines

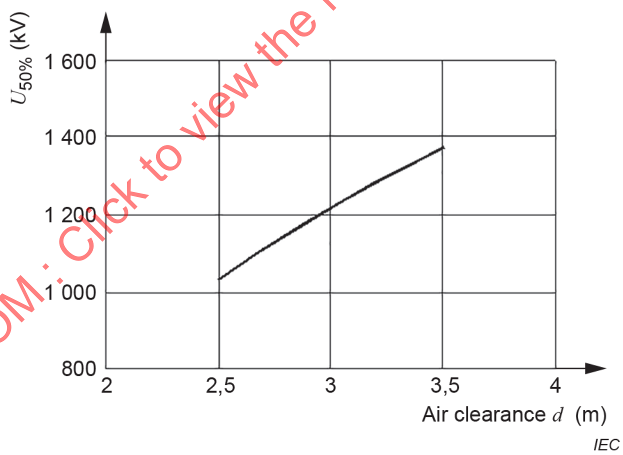


Figure D.8 – The power frequency flashover voltage characteristic of air clearance from bottom-phase conductor (with I-type string) to tower body of 1 000 kV double-circuit lines

D.2.2 50 % Switching impulse flashover voltage test results for air clearances of transmission line structures

The wind speed concurrent with switching overvoltage is generally taken as 50 % of the basic wind speed and the time to peak of the switching impulse test waveform for UHV AC lines is generally taken as 1 000 us. See Figure D.9 and Figure D.10 for arrangement of switching impulse flashover voltage test of 1 000 kV line.

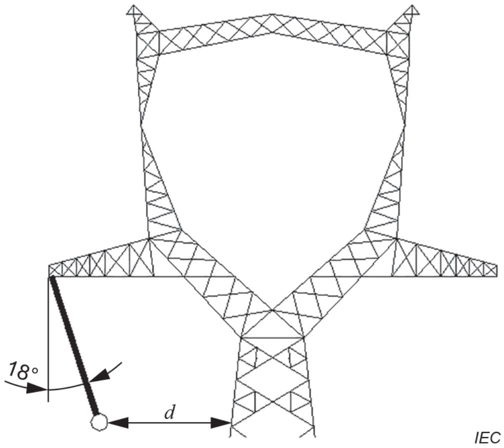


Figure D.9 – The arrangement of switching impulse flashover voltage test for side-phase air clearances of 1 000 kV cat-head type towers

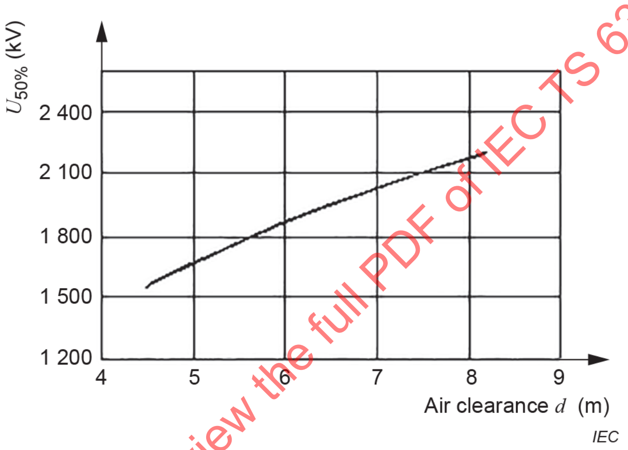


Figure D.10 – The 50 % switching impulse flashover voltage characteristic for air clearances from conductor to tower body of 1 000 kV lines (with a time to peak of 250 μs)

When the air clearance from the side-phase conductor (with I-type string) to tower leg with swing angle considered is 5,6 m, and the switching impulse test results with different test time to peak are as shown in Table D.1.

Table D.1 – Switching impulse flashover voltages of side-phase air clearances of 1 000 kV cat-head type towers with different test time to peak

time to peak μs	250	500	1 000	5 000
$U_{50\ \%}$ kV	1 789	1 880	1 915	2 125

Dimensions in metres

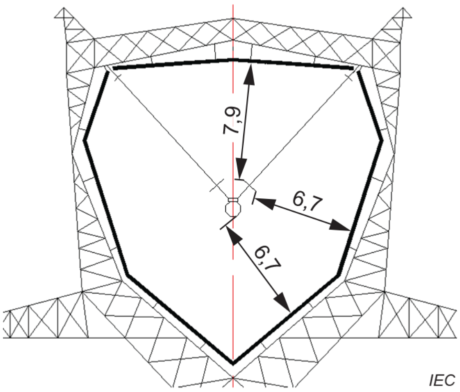


Figure D.11 – The arrangement of switching impulse flashover voltage test for middle-phase air clearances of 1 000 kV cat-head type towers

Figure D.11 shows the arrangement of switching impulse flashover voltage test for middle-phase air clearances, and Table D.2 lists the switching impulse flashover voltage test results of air clearances from conductor to tower window with different test time to peak. Table D.3 lists the switching impulse flashover voltage for air clearance from the middle-phase conductor to tower window in the arrangement shown in Figure D.14 a) and Figure D.14 b). Figure D.12 and Figure D.13 show the arrangement of switching impulse flashover voltage test for side-phase air clearances of 1 000 kV cup type towers and the 50 % switching impulse flashover voltage characteristic for air clearances from conductor to tower body of 1 000 kV lines. Figures D.14 to D.26 show the switching impulse flashover voltage test result for 1 000 kV lines.

Table D.2 – The switching impulse flashover voltage of air clearances from middle-phase conductor to tower for 1 000 kV full-scale towers

time to peak µs	250	1 000	5 000
$U_{50\ \%}$ kV	1 801	2 015	2 149

Dimensions in metres

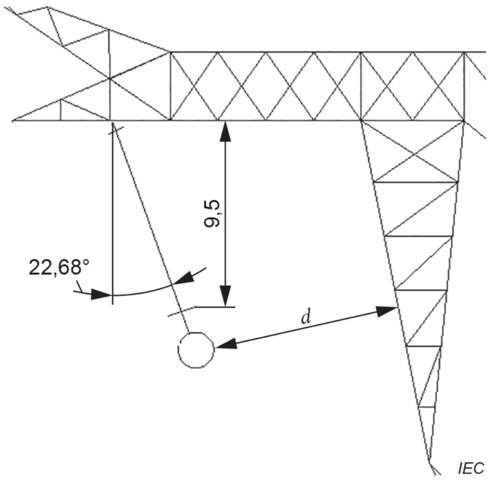


Figure D.12 – The arrangement of switching impulse flashover voltage test for side-phase air clearances of 1 000 kV cup type towers

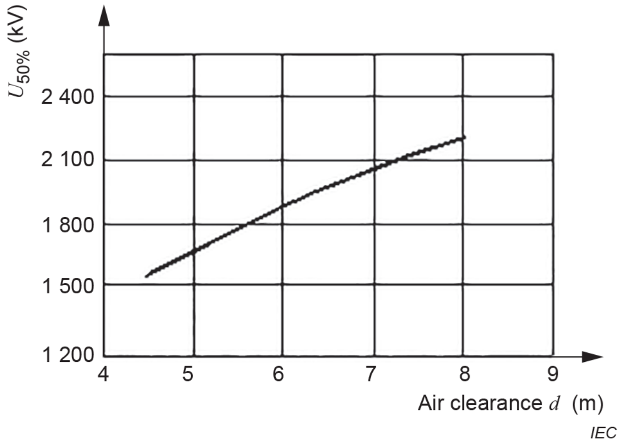
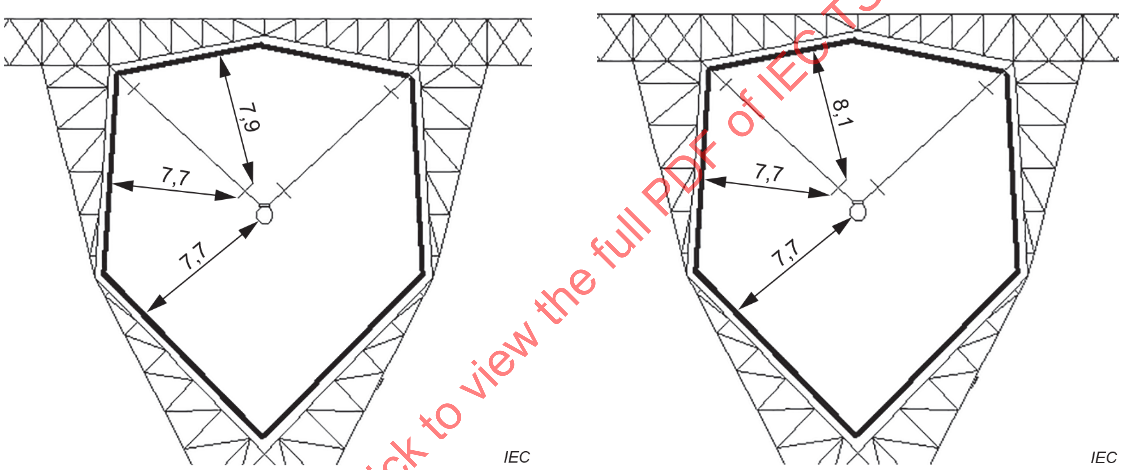


Figure D.13 – The 50 % switching impulse flashover voltage characteristic for air clearances from conductor to tower body of 1 000 kV lines (with a time to peak of 250 μs)

Dimensions in metres



a) Middle-phase 7,9 m **b) Middle-phase 8,1 m**

Figure D.14 – The arrangement of switching impulse flashover voltage test for middle-phase air clearances of 1 000 kV cup type towers

Table D.3 – The switching impulse flashover voltage for air clearance from the middle-phase conductor to tower window in the arrangement shown in Figure D.14 a) and Figure D.14 b)

time to peak (μs)		250	1 000	5 000
Figure D.14 a)	U_{50} (kV)	1 862	2 035	2 217
Figure D.14 b)	U_{50} (kV)	1 909	2 064	2 248

Dimensions in metres

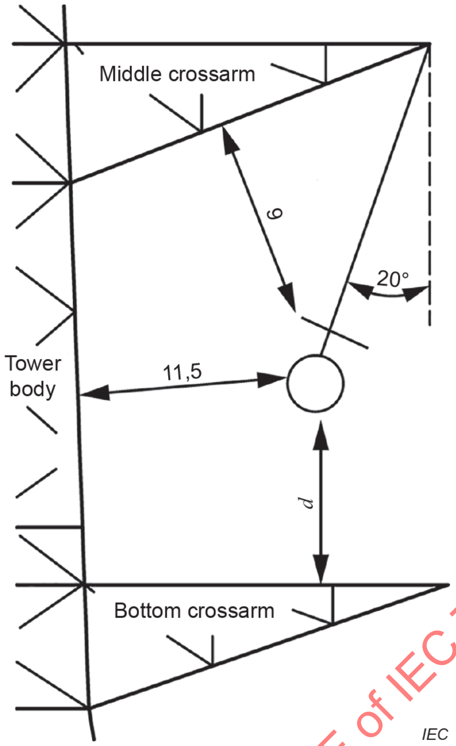


Figure D.15 – The arrangement of switching impulse flashover voltage test at long time to peak for middle-phase air clearances (with I-type string) of 1 000 kV double-circuit lines

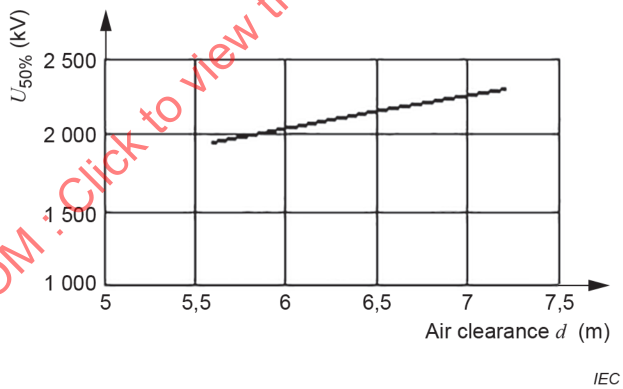


Figure D.16 – The 50 % switching impulse (1 000 µs) flashover voltage characteristic for air clearances from conductor to bottom crossarm of 1 000 kV double-circuit lines (a distance of 9,0 m between conductor and middle crossarm)

Dimensions in metres

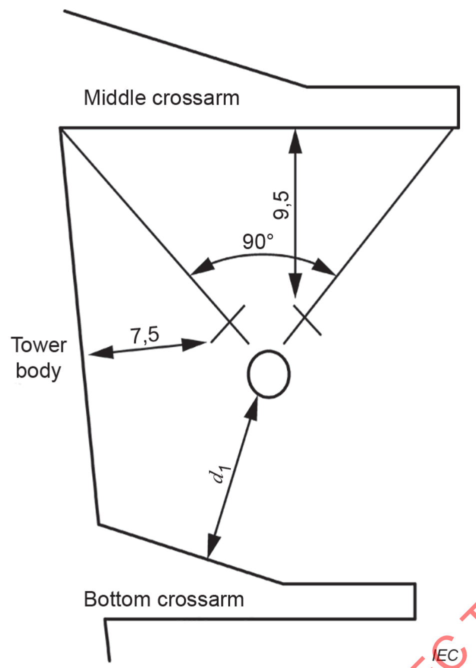


Figure D.17 – The arrangement of switching impulse flashover voltage test for air clearances from middle-phase conductor (with V-type string) to bottom crossarm of 1 000 kV double-circuit lines

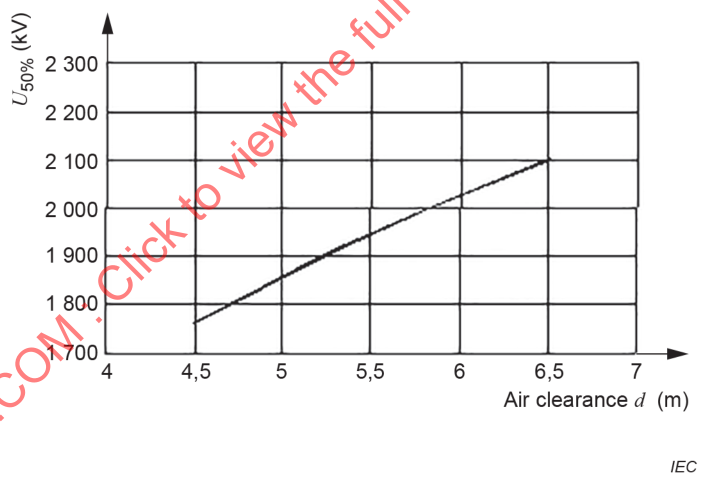


Figure D.18 – The 50 % switching impulse (1 000 µs) flashover voltage characteristic of air clearances from conductor to bottom crossarm of 1 000 kV double-circuit lines

Dimensions in metres

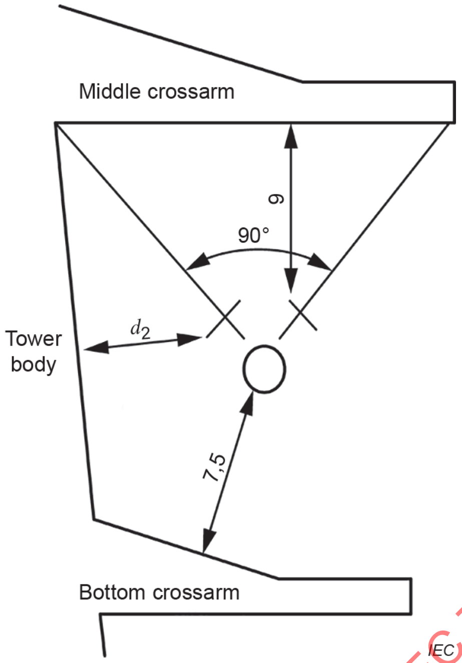


Figure D.19 – The arrangement of switching impulse flashover test for air clearances from middle-phase conductor (with V-type string) to tower body of 1 000 kV double-circuit lines

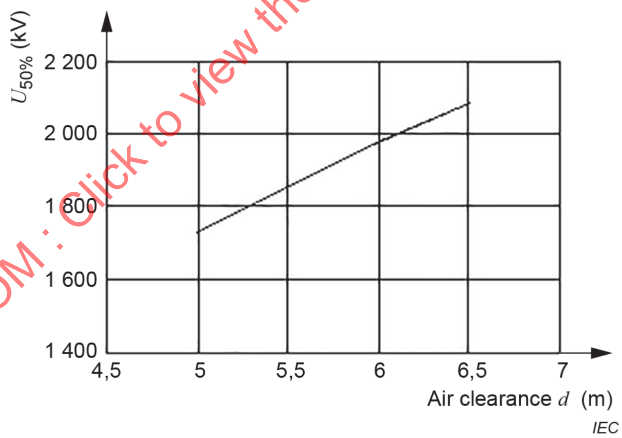


Figure D.20 – The 50 % switching impulse (1 000 µs) flashover voltage characteristic for air clearances from conductor to tower body of 1 000 kV double-circuit lines

Dimensions in metres

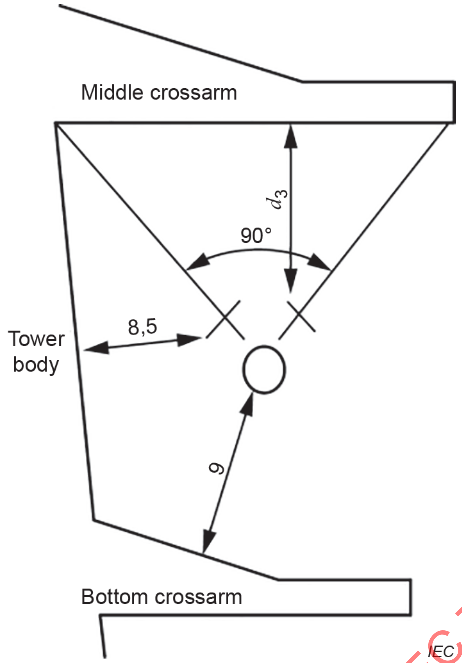


Figure D.21 – The arrangement of switching impulse flashover voltage test for air clearances from middle-phase conductor (with V-type string) to middle crossarm of 1 000 kV double-circuit lines

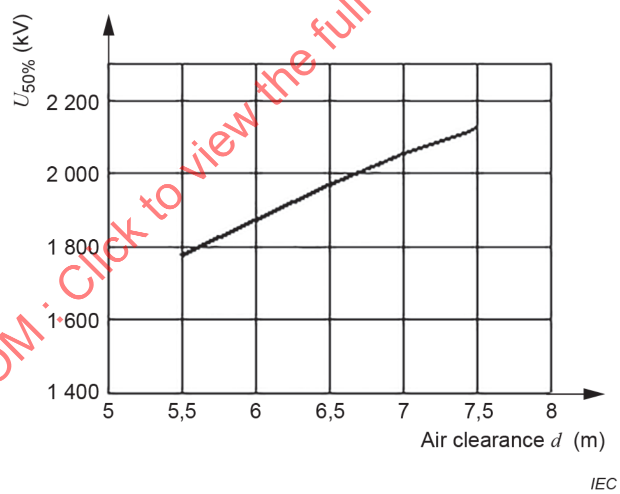


Figure D.22 – The 50 % switching impulse (1 000 μs) flashover voltage characteristic for air clearances from conductor to middle crossarm of 1 000 kV double-circuit lines

Dimensions in metres

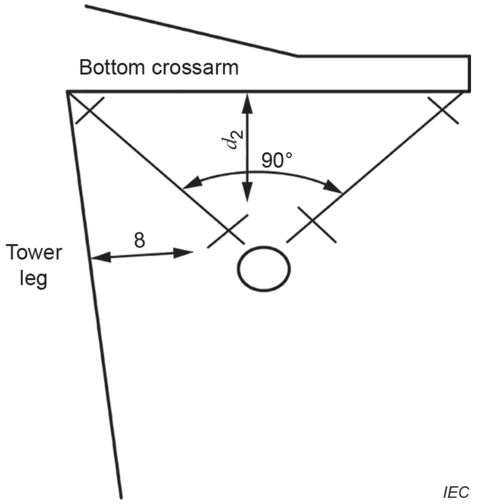


Figure D.23 – The arrangement of switching impulse flashover voltage test for air clearances from bottom-phase conductor (with V-type string) to crossarm of 1 000 kV double-circuit lines

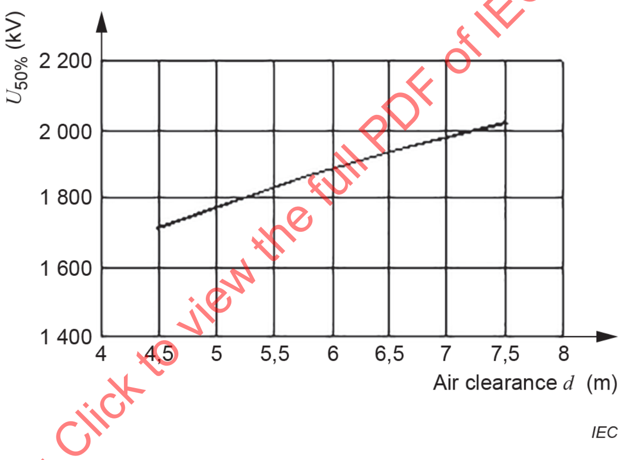


Figure D.24 – The 50 % switching impulse (1 000 µs) flashover voltage characteristic for air clearances from conductor to crossarm of 1 000 kV double-circuit lines

Dimensions in metres

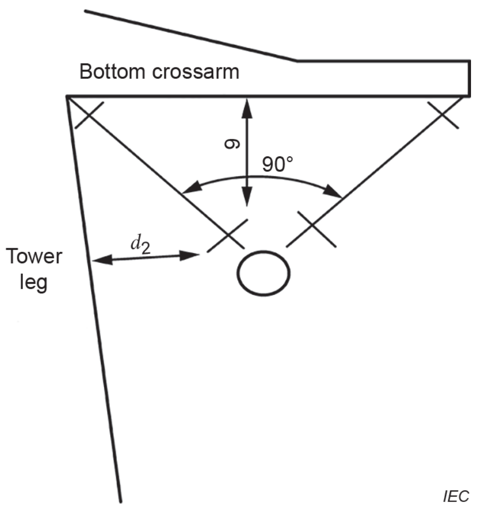


Figure D.25 – The arrangement of switching impulse flashover voltage test for air clearances from bottom-phase conductor (with V-type string) to tower body of 1 000 kV double-circuit lines

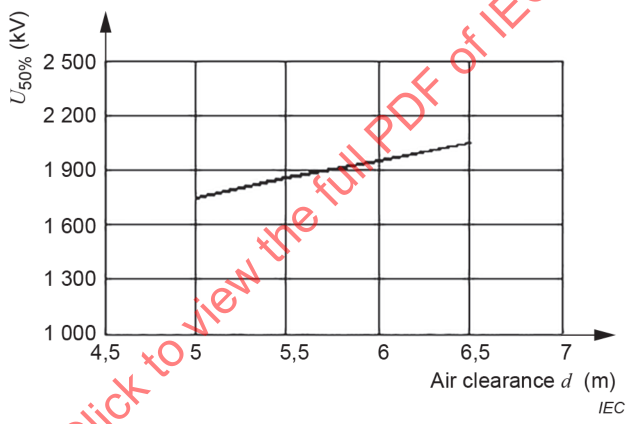


Figure D.26 – The 50 % switching impulse (1 000 µs) flashover voltage characteristic for air clearances from conductor to tower body of 1 000 kV double-circuit lines

D.2.3 50 % Lightning impulse flashover voltage test results for air clearances of transmission line structures

The concurrent wind speed for lightning overvoltage is generally taken as 10 m/s. Figures D.27 to D.31 show the lightning impulse flashover voltage test for 1 000 kV lines.