



**BSI Standards Publication**

## **UHV AC transmission systems**

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Part 202: UHV AC Transmission line design

## National foreword

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**UHV AC TRANSMISSION SYSTEMS –****Part 202: UHV AC Transmission line design****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,

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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](http://webstore.iec.ch) in the data related to the specific document. At this date, the document will be

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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:

$$n \geq \frac{\lambda V_m}{\sqrt{3} K_e L_1} \quad (1)$$

where

$n$  is the number of insulators required for each string;

$\lambda$  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;

$L_1$  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:

$$n \geq \frac{V_m}{\sqrt{3} V_{50\%} (1 - n\sigma)} \quad (2)$$

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;

$\sigma$  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<sup>2</sup>, no correction is required; if ESDD is greater than 0,1 mg/cm<sup>2</sup>, 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<sup>2+</sup> in composite salt). If the corrected ESDD is smaller than 0,1 mg/cm<sup>2</sup>, it can be taken as 0,1 mg/cm<sup>2</sup>.

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).

$$I = \sqrt{\frac{q_c + q_r - q_s}{R(T_c)}} \quad (3)$$

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  $T_c$  [ $\Omega$ /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, hardware 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 to 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:

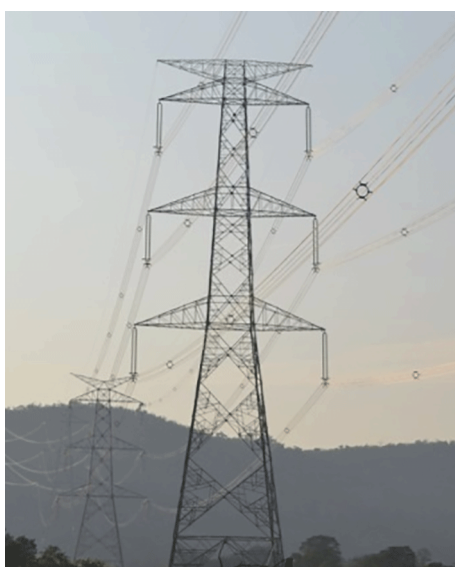
- a) **Vertical or Barrel type configuration:** Such type of configurations, involving vertical arrangement of phase conductors, are prevalent in single circuit, double circuit as well as multi-circuit transmission lines. In case of single circuit tower configurations, while the top phase is placed either 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



**Figure 3 – Typical single circuit horizontal configuration tower**



**Figure 4 – Typical single circuit delta configuration tower**

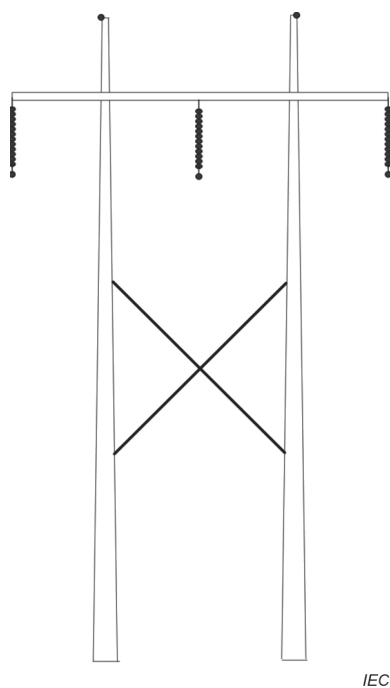


**Figure 5 – Typical single circuit H-type tower**

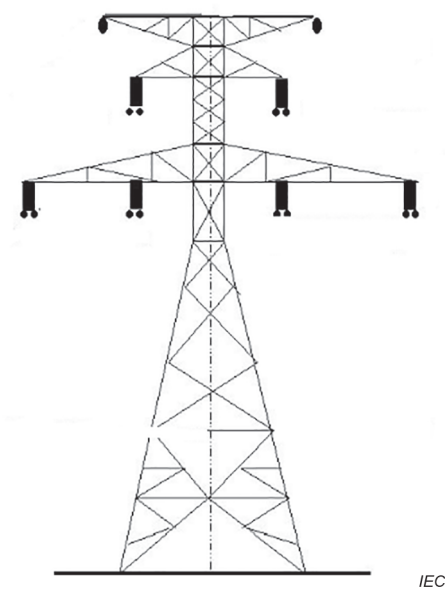


**Figure 6 – Typical double circuit danube configuration tower**



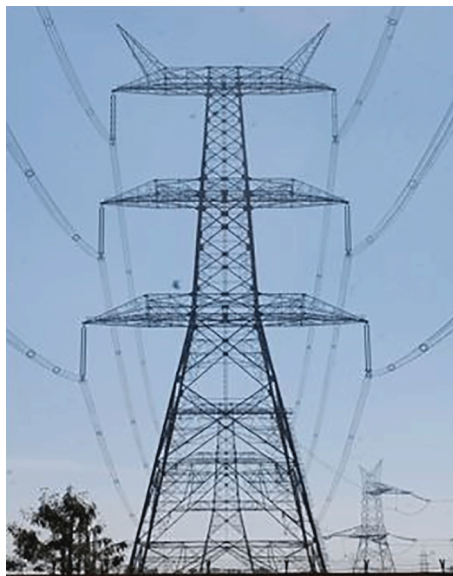
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**Figure 7 – 1 200 kV single circuit vertical configuration tower**



IEC

**Figure 8 – 1 200 kV single circuit horizontal configuration tower**



IEC

**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/constraints. 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 determined

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 towers 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

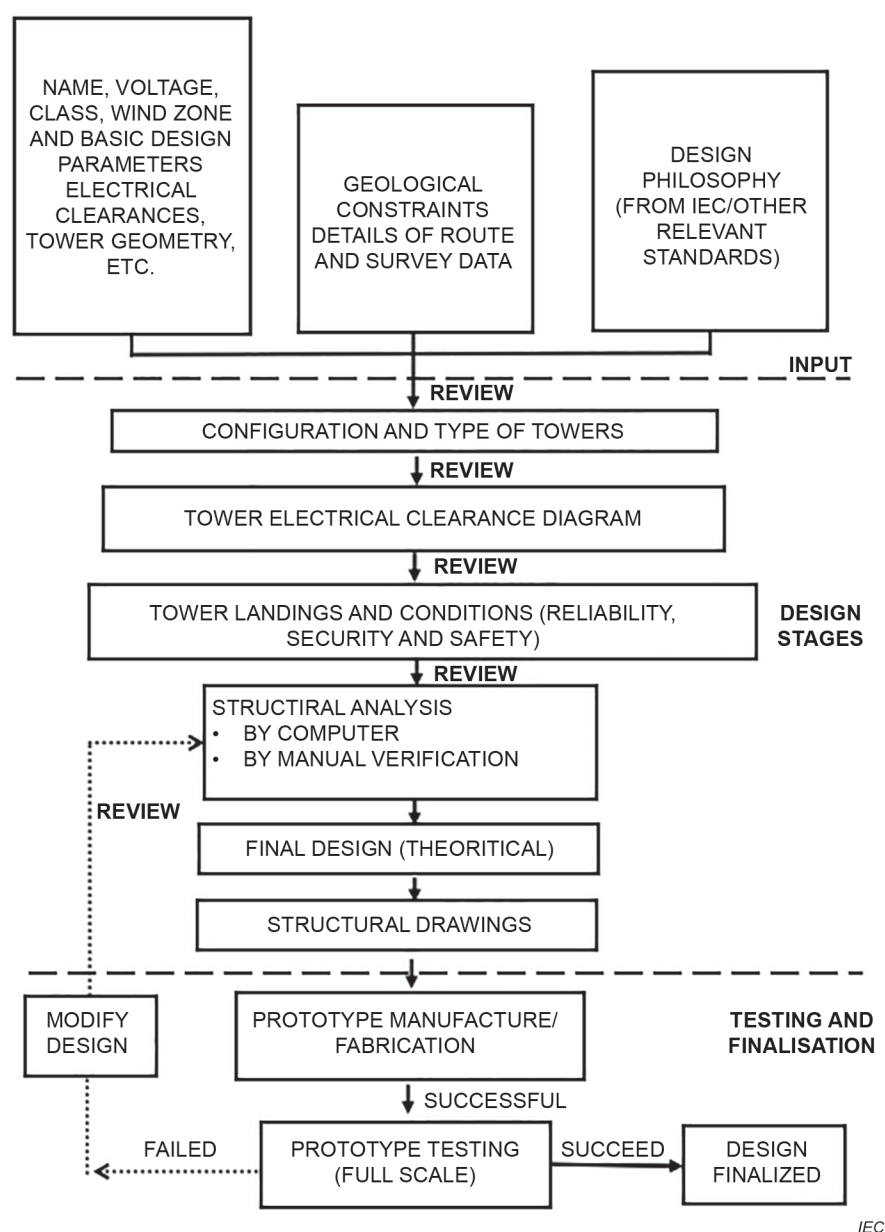


Figure 11 – Tower design methodology

## 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