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Overhead transmission lines — Design criteria



National foreword

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INTERNATIONAL STANDARD



Overhead transmission lines – Design criteria

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

OVERHEAD TRANSMISSION LINES – DESIGN CRITERIA**FOREWORD**

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International Standard IEC 60826 has been prepared by IEC technical committee 11: Overhead lines.

This fourth edition cancels and replaces the third edition published in 2003. It constitutes a technical revision.

The main technical changes with regard to the previous edition are as follows:

This standard has been further simplified by removing many informative annexes and theoretical details that can now be found in CIGRE Technical Brochure 178 and referred to as needed in the text of the standard. Many revisions have also been made that reflect the users experience in the application of this standard, together with information about amplification of wind speed due to escarpments. The annexes dealing with icing data have also been updated using new work by CIGRE.

The text of this standard is based on the following documents:

FDIS	Report on voting
11/251/FDIS	11/252/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

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

- reconfirmed,
- withdrawn,
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- amended.

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OVERHEAD TRANSMISSION LINES – DESIGN CRITERIA

1 Scope

This International Standard specifies the loading and strength requirements of overhead lines derived from reliability-based design principles. These requirements apply to lines 45 kV and above, but can also be applied to lines with a lower nominal voltage.

This document also provides a framework for the preparation of national standards dealing with overhead transmission lines, using reliability concepts and employing probabilistic or semi-probabilistic methods. These national standards will need to establish the local climatic data for the use and application of this standard, in addition to other data that are country-specific.

Although the design criteria in this standard apply to new lines, many concepts can be used to address the design and reliability requirements for refurbishment, upgrading and uprating of existing lines.

This document does not cover the detailed design of line components such as supports, foundations, conductors or insulators strings.

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 60652, *Loading tests on overhead line structures*

IEC 61089, *Round wire concentric lay overhead electrical stranded conductors*

IEC 61773, *Overhead lines – Testing of foundations for structures*

IEC 61774, *Overhead lines – Meteorological data for assessing climatic loads*

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

3 Terms, definitions, symbols and abbreviations

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

3.1 Terms and definitions

3.1.1

characteristic strength

guaranteed strength, minimum strength, minimum failing load

R_c

strength value guaranteed in appropriate standards

Note 1 to entry: This value usually corresponds to an exclusion limit, from 2 % to 5 %, with 10 % being an upper practical (and conservative) limit.

3.1.2**coefficient of variation***COV*

ratio of the standard deviation to the mean value

Note 1 to entry: The *COV* of load and strength are respectively denoted by ν_Q and ν_R .

3.1.3**components**

different parts of a transmission line system having a specified purpose

Note 1 to entry: Typical components are supports, foundations, conductors and insulator strings.

3.1.4**damage limit (of a component)****serviceability limit state**

strength limit of a component corresponding to a defined limit of permanent (or inelastic) deformation of this component which leads to damage to the system if it is exceeded

Note 1 to entry: This limit is also called the serviceability limit state in building codes based on limit states design.

3.1.5**damage state (of the system)**

state where the system needs repairing because one of its components has exceeded its damage limit

Note 1 to entry: The system needs repairing because it is not capable of fulfilling its task under design loads or because design clearances may be reduced (e.g. conductor to ground).

3.1.6**elements**

different parts of a component

Note 1 to entry: For example, the elements of a steel lattice tower are steel angles, plates and bolts.

3.1.7**exclusion limit***e* %value of a variable taken from its distribution function and corresponding to a probability of *e* % of not being exceeded**3.1.8****failure limit (of a component)****ultimate limit state**

strength limit of a component which leads to the failure of the system if this limit is exceeded

Note 1 to entry: If this strength limit is exceeded, the system will reach a state called "ultimate limit state" as defined in building codes based on limit states design.

3.1.9**failure state (of the system)**

state of a system in which a major component has failed because one of its components has reached its failure limit (such as by rupture, buckling, overturning)

Note 1 to entry: This state leads to the termination of the ability of the line to transmit power and needs to be repaired.

3.1.10**intact state**

state in which a system can accomplish its required function and can sustain limit loads

3.1.11**limit load** Q_T

climatic load corresponding to a return period, T , used for design purposes without additional load factors

Note 1 to entry: Refer to 5.2.1.

3.1.12**load factor** γ

factor to be multiplied by the limit load in order to design line components

3.1.13**operating period**

general measure of useful (or economical) life

Note 1 to entry: Typical operating periods of transmission lines vary from 30 years to 80 years.

3.1.14**reference wind speed** V_R

wind speed at 10 m in height, corresponding to an averaging period of 10 min and having a return period T

Note 1 to entry: When this wind speed is taken in a terrain type B, which is the most common case in the industry, the reference wind speed is identified as V_{RB} .

3.1.15**reference ice load** g_R or t_R

reference limit ice loads (g_R is a unit ice weight and t_R is a uniform radial ice thickness around the conductor) having a return period T

3.1.16**reliability (structural)**

probability that a system performs a given task, under a set of operating conditions, during a specified time

Note 1 to entry: Reliability is thus a measure of the success of a system in accomplishing its task. The complement to reliability is the probability of failure or unreliability.

3.1.17**return period (of a climatic event)** T

average occurrence in years of a climatic event having a defined intensity

Note 1 to entry: The inverse of the return period is the yearly frequency which corresponds to the probability of exceeding this climatic event in a given year.

3.1.18**safety**

ability of a system not to cause human injuries or loss of lives

Note 1 to entry: In this document, safety relates mainly to protection of workers during construction and maintenance operations. The safety of the public and of the environment in general is covered by national regulations.

3.1.19**security (structural)**

ability of a system to be protected from a major collapse (cascading effect) if a failure is triggered in a given component

Note 1 to entry: Security is a deterministic concept as opposed to reliability which is a probabilistic concept.

3.1.20**strength factor** Φ

factor applied to the characteristic strength of a component

Note 1 to entry: This factor takes into account the coordination of strength, the number of components subjected to maximum load, quality and statistical parameters of components.

3.1.21**system**

set of components connected together to form the transmission line

3.1.22**task**

function of the system (transmission line), i.e. to transmit power between its two ends

3.1.23**unavailability**

inability of a system to accomplish its task

Note 1 to entry: Unavailability of transmission lines results from structural unreliability as well as from failure due to other events such as landslides, impact of objects, sabotage, defects in material, etc.

3.1.24**use factor** U

ratio of the actual load (as built) to limit load of a component

Note 1 to entry: For tangent supports, it is virtually equal to the ratio of actual to maximum design spans (wind or weight) and for angle supports; it also includes the ratio of the sines of the half angles of deviation (actual to design angles).

3.2 Symbols and abbreviations

a	Unit action of wind speed on line elements (Pa or N/m ²)
A_c	Wind force on conductors (N)
A_i	Wind force on insulators (N)
A_t	Wind force acting on a tower panel made of steel angles, A_{tc} for cylindrical tower members (N)
B_i	Reduction factor of the reference wind speed for wind and ice combinations
C_x	Drag coefficient (general form)
C_i	Drag coefficient of ice covered conductors (C_{iL} for low probability and C_{iH} for a high probability)
C_{xc}	Drag coefficient of conductors
C_{xi}	Drag coefficient of insulators
C_{xt}	Drag coefficient of supports C_{xt1} , C_{xt2} for each tower face (C_{xtc} on cylindrical tower members)
COV	Coefficient of variation, also identified as v_x (ratio of standard deviation to mean value)

d	Conductor diameter (m)
d_{tc}	Diameter of cylindrical tower members (m)
D	Equivalent diameter of ice covered conductors (D_H for high probability and D_L for low probability) (m)
e	Exclusion limit (%)
e_N	Exclusion limit of N components in series (%)
$F_{(x)}$	Cumulative distribution function of variable x
G	Wind factor (general form)
G_c	Combined wind factor of conductors
G_t	Combined wind factor of towers
G_L	Span factor for wind calculations
g	Unit weight of ice (N/m)
g_m	Yearly maximum ice load (N/m)
$\overline{g}_m$	Mean yearly maximum ice loads (N/m)
g_{max}	Maximum weight of ice per unit length observed during a certain number of years (N/m)
g_R	Reference design ice weight (N/m)
g_H	Ice load having a high probability (N/m)
g_L	Ice load having a low probability (N/m)
H	Horizontal tensile load
K_R	Terrain roughness factor
K_d	Diameter factor related to the influence of conductor diameter
K_h	Height factor to be multiplied by $\overline{g}$ to account for the influence of height above ground
K_n	Factor to be multiplied by $\overline{g}$ to account for the influence of the number of years with icing observations
l_e	Length of a support member (m)
L	Span length or wind span (m)
L_m	Average span (m)
n	Number of years of observation of a climatic event
N	Number of components subjected to maximum loading intensity
Q	General expression used to identify the effects of weather related loads on lines and their components
Q_T	The system limit load corresponding a return period T
q_0	Dynamic reference wind pressure due to reference wind speed V_R (q_{0L} , q_{0H} for low and high probability) (Pa or N/m ²)
Re	Reynolds number
R	Strength (usually in Pa or in kN depending on components)
$\overline{R}$	Mean strength (units same as for R)
R_c	Characteristic strength (units same as for R)
$(e)R$	Exclusion limit (e) of strength (units same as for R)
RSL	Residual static load of a broken conductor (kN)
S_i	Projected area of insulators (m ²)

S_t	Projected area of a tower panel (m^2)
t	Ice load expressed in uniform radial ice thickness around the conductor (mm)
t_R	Reference ice load expressed in uniform radial thickness around the conductor (mm)
T	Return period of weather events (years)
u	Number of standard deviations between mean strength and characteristic strength
U	Use factor
v_x	Coefficient of variation (COV) of variable x
V	Wind speed (m/s)
V_m	Yearly maximum wind speed (m/s)
$\bar{V}_m$	Mean yearly maximum wind speed (m/s)
V_G	Yearly maximum gradient wind speed (m/s)
$\bar{V}_G$	Mean yearly maximum gradient wind speed (m/s)
V_R	Reference wind speed (m/s)
V_{iL}	Low probability wind speed associated with icing (m/s)
V_{iH}	High probability wind speed associated with icing (m/s)
w	Unit weight of conductor or ground wire (N/m)
$\bar{x}$	Mean value of variable x
Y	Horizontal distance between foundations of a support (m)
z	Height above ground of conductors, centre of gravity of towers panels, or insulator strings (m)
γ	Load factor (general form)
γ_U	Use factor coefficient
γ_{TW}	Load factor to adjust the 50 year wind speed to a return period T
γ_{Tt}	Load factor to adjust the 50 year ice thickness to a return period T
γ_{TiW}	Load factor to adjust the 50 year ice weight to a return period T
δ	Ice density (kg/m^3)
Φ	Strength factor (general form)
Φ_R	Global strength factor
Φ_N	Strength factor due to number of components subjected to maximum load intensity
Φ_S	Strength factor due to coordination of strength
Φ_Q	Strength factor due to quality
Φ_c	Strength factor related to the characteristic strength R_c
σ_x	Standard deviation of variable x
σ_g	Standard deviation of yearly maximum ice loads (N/m)
μ	Mass of air per unit volume (kg/m^3)
τ	Air density correction factor
ν	Kinetic air viscosity (m^2/s)

Ω	Angle between wind direction and the conductor (degrees)
θ	Angle of incidence of wind direction with the tower panel (degrees)
θ'	Angle of incidence of wind direction with cylindrical elements of tower (degrees)
χ	Solidity ratio of a tower panel

4 General

4.1 Objective

This document serves either of the following purposes:

- a) It provides design criteria for overhead lines based on reliability concepts. The reliability based method is particularly useful in areas where significant amounts of meteorological and strength data are readily available. This method may however be used for lines designed to withstand specific climatic loads, either derived from experience or through calibration with existing lines that had a long history of satisfactory performance. In these cases, design consistency between strengths of line components will be achieved, but actual reliability levels may not be known, particularly if there has been no evidence or experience with previous line failures.

It is important to note that the design criteria in this standard do not constitute a complete design manual for transmission lines. However, guidance is given on how to increase the line reliability if required, and to adjust the strength of individual components to achieve a desired coordination of strength between them.

- b) It provides a framework for the preparation of national standards for transmission lines using reliability concepts and employing probabilistic or semi-probabilistic methods. These national standards will need to establish the climatic data for the use and application of this standard in addition to other data specific to each country.

This standard also provides minimum safety requirements to protect people and construction/maintenance personnel from injury, as well as to ensure an acceptable level of service continuity (safe and economical design).

The design criteria in this standard apply to new line conditions. It is however a fact of life that transmission lines age and lose strength with time. The amount of strength reduction due to ageing is difficult to generalize, as it varies from one component to another, and also depends on the type of material, the manufacturing processes and the environmental influences. This issue is currently being studied by relevant technical bodies.

The requirements are specified in this standard, while, in Annexes A to G, additional informative data and explanations are given.

4.2 System design

The methodology is based on the concept whereby a transmission line is designed as a system made of components such as supports, foundations, conductors and insulator strings. This approach enables the designer to coordinate the strengths of components within the system and recognizes the fact that a transmission line is a series of components where the failure of any component could lead to the loss of power transmitting capability. It is expected that this approach should lead to an overall economical design without undesirable mismatch.

As a consequence of such a system design approach, it is recognized that line reliability is controlled by that of the least reliable component.

An overhead transmission line can be divided into four major components as shown in Figure 1. Subsequently, each component may be divided into different elements.

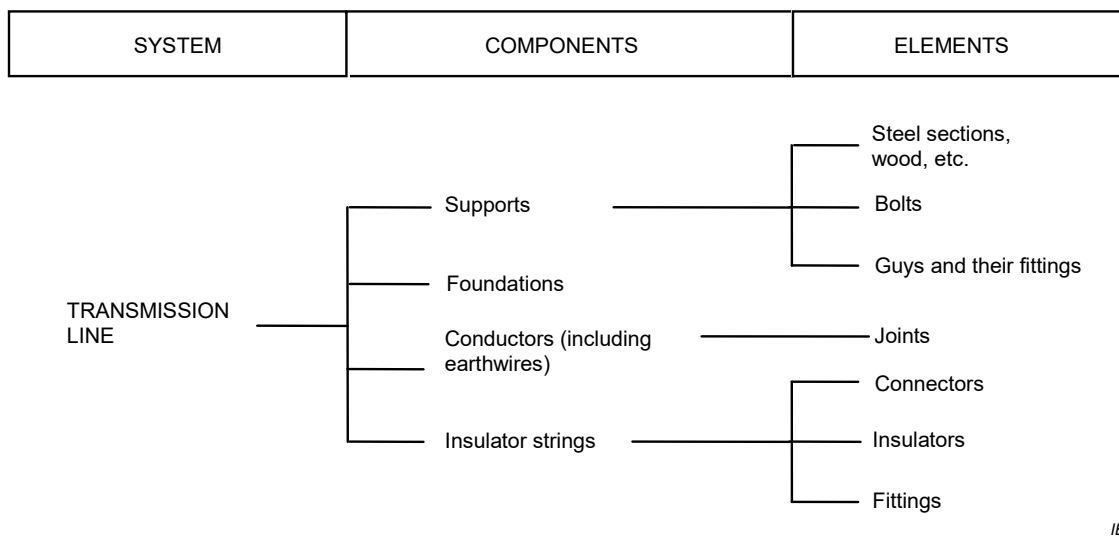


Figure 1 – Diagram of a transmission line

4.3 System reliability

The objective of design criteria described in this standard is to provide for reliable and safe lines. The reliability of lines is achieved by providing strength requirements of line components larger than the quantifiable effects of specified weather related loads. These climatic loads are identified in this standard as well as means to calculate their effects on transmission lines. However, it has to be recognized that other conditions, not usually dealt with in the design process, can occur and can lead to line failure such as impact of objects, defects in material, etc. Some measures, entitled security requirements, included in this standard provide lines with enough strength to reduce damage and its propagation, should it occur.

5 General design criteria

5.1 Methodology

5.1.1 General

The recommended methodology for designing transmission line components is summarized in Figure 2 and can be described as follows:

- a) Collect preliminary line design data and available climatic data.

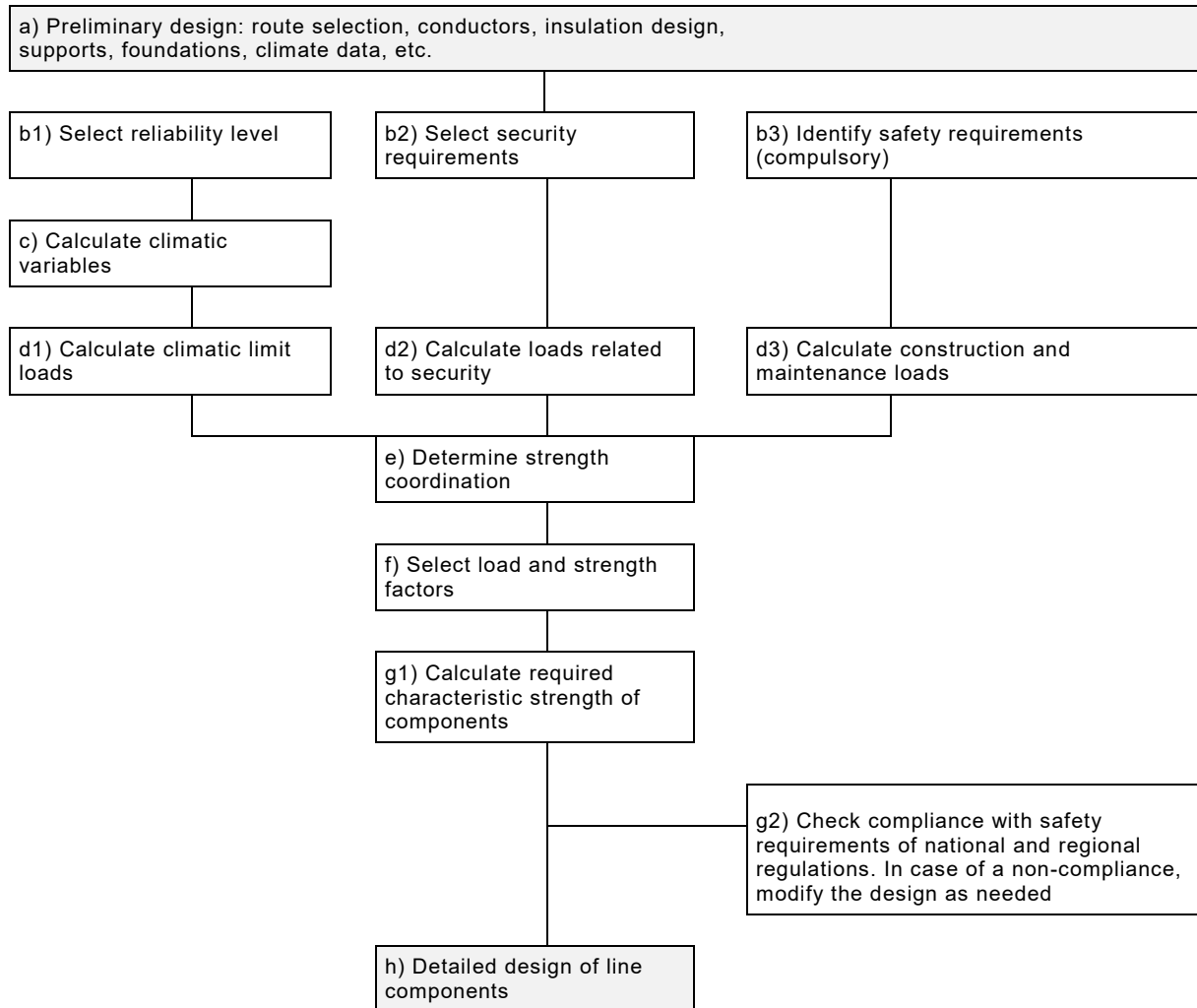
NOTE 1 In some countries, reference wind speed, such as the 50 year return period, is given in national standards.

- b1) Select the reliability level in terms of return period of limit loads.
- b2) Select the security (failure containment) requirements.
- b3) Identify safety requirements imposed by mandatory regulations and construction and maintenance loads.
- c) Calculate climatic variables corresponding to selected return period of limit loads.
- d1) Calculate climatic limit loads on components.
- d2) Calculate loads corresponding to security requirements.
- d3) Calculate loads related to safety requirements during construction and maintenance.
- e) Determine the suitable strength coordination between line components.
- f) Select appropriate load and strength factors applicable to load and strength formulas.
- g1) Calculate the characteristic strengths required for components.

g2) Check compliance with national safety regulations, and adjust the design if non-compliant.

h) Design line components for the above strength requirements.

This standard deals with items b) to g2). Items a) and h) are not part of the scope of this standard. They are identified by a shaded frame in Figure 2.



IEC

Figure 2 – Transmission line design methodology

5.1.2 Reliability requirements

5.1.2.1 Reliability levels (weather related loads)

Reliability requirements aim to ensure that lines can withstand the defined climatic events (wind, ice, ice and wind, having a return period T) and the loads derived from these events during the projected life cycle of the system and can provide service continuity under these conditions.

Transmission lines can be designed for different reliability levels (or classes). For the purposes of this standard, the reference reliability level is defined as the reliability of a line designed for a 50 year return period climatic event associated with a 10 % exclusion limit of strength (applies to the components selected as the least reliable). This reference reliability level is generally regarded as providing an acceptable reliability level in respect of continuity of service and safety.

Lines can be designed for higher reliability levels by increasing the return period T of climatic events. A higher reliability can be justified for example by the importance of the line in the network. Three reliability levels are proposed in this standard and are assumed to cover the range of values to be considered for most transmission lines. These levels are expressed in terms of return periods of climatic events as shown in Table 1. For temporary lines, some wooden poles or lines of limited importance, return periods of about 25 years may be appropriate.

Table 1 – Reliability levels for transmission lines

Reliability levels	1	2	3
T , return period of climatic event, in years	50	150	500

NOTE Some national regulations and/or codes of practice, sometimes impose, directly or indirectly, design requirements that may restrict the choices offered to designers.

Other values of T in the range of 50 to 500 years, such as 100, 200 and 400 years, can be used if justified by local conditions.

In some cases, individual utility's requirements can dictate other reliability levels depending on the proper optimization between initial cost of the line and future cost of damage, as well as on uncertainties related to input design parameters.

5.1.2.2 Approximate values for yearly reliability

Both loads (Q) and strengths (R) are stochastic variables and the combined reliability is computable if the statistical functions of load Q and strength R are known. The condition for a line to be reliable is when loads effects are less than the strength withstand of the line. The reliability and probability of failure are complements to 1 as indicated by the following Formula (1).

$$\text{Yearly reliability (probability of survival)} = 1 - \text{yearly probability of failure} \quad (1)$$

When the characteristic strength, deemed to be the strength being exceeded with 90 % probability (i.e. the exclusion limit is 10 %, or $(10\%)R$), is set equal to the climatic load corresponding to the selected return period T , designated Q_T , various probabilistic combinations lead to a theoretical yearly minimum reliability of around $(1 - 1/2T)$. This association between load and strength is given by the following Formula (2)¹:

$$Q_T = (10\%) R \quad (2)$$

Throughout the present standard, the loading Q_T is called the system limit load having a return period T .

The actual reliability can be different if load and strength data are not sufficiently accurate or available. In the latter case, the absolute reliability may not be known, but its value relative to a reference design may be computed if new line parameters are comparable to the reference values.

The relationship expressed in Formula (2) can be further refined through the introduction of correction factors related to the following items:

¹ Additional information and background data related to reliability based design of overhead lines can be found in the following CIGRÉ publications and brochures: Technical Brochures 109 and 178 (Chapter 2), *Electra* papers 1991-137 and 2000-189.

- use factors of components: the fact that all components are not used at their maximum design parameter (wind span, weight span, height of support, line angle) contributes to an increase of the reliability;
- characteristic strength R_C : in actual lines, the characteristic strength of most components corresponds to an exclusion limit less than 10 %. If, in such cases, it is assumed to be equal to 10 %, then the actual reliability of the line will be higher;
- strength coordination: a selected strength coordination results in an increase of strength or withstand resistance of some components;
- number of components subjected to maximum loading intensity: whenever a storm or severe icing occurs, not all structures will be subjected to maximum loads, since the storm is limited in spatial extension;
- quality control during fabrication and construction: by these measures, low quality material will be eliminated. No components with strengths below a certain limit will be used;
- critical wind direction: in case of wind loads it generally is assumed for design purposes that maximum wind velocities also act in the most unfavourable direction. However, maximum winds are distributed in angle sectors. Approximate calculations carried out by the CIGRE Working Group SC 22.06 showed that more realistic assumptions could reduce the probability of failure by one order of magnitude.

In practice, if the above factors are not properly taken into account in Formula (2), then the resulting reliability will be different from the theoretical values.

While the above-mentioned factors contribute to the actual reliability usually being higher than the theoretical values, other factors could lead to opposite effects, i.e. a reduction in reliability. For example, the ageing of some line components and the fatigue due to a large number of loading cycles will have a negative effect on reliability.

It is noted that requirements for other events such as earthquakes are not covered in this standard.

NOTE Usually, transmission structures are not affected by earthquake loads because they are already designed for important horizontal wind and longitudinal loads that are applied on the higher points of the structure.

It is also noted that the above probability of failure is only one of the components of the total line unavailability as described in 3.1.23.

5.1.3 Security requirements

Security requirements correspond to special loads and/or measures intended to reduce probability of uncontrollable progressive (or cascading) failures that may extend well beyond an initial failure. These measures are detailed in 6.6.

NOTE Some security measures, such as those providing longitudinal strength of broken conductor loads for failure containment can also lead to an increase in reliability to withstand unbalanced ice loads.

5.1.4 Safety requirements

Safety requirements consist of special loads for which line components (mostly support members) have to be designed, to ensure that construction and maintenance operations do not pose additional safety hazards to people. These measures are detailed in 6.5.

5.2 Load-strength requirements

5.2.1 Climatic loads

Loads associated with climatic events are random variables. Three weather-related loading conditions are recognized: wind, ice, and wind and ice combined. When statistical data of wind and/or ice are available, these can be used to compute the limit load Q_L for each component exposed to the climatic event under consideration.

In the calculation process for each component, the following condition has to be checked:

$$\text{Design limit load} < \text{design strength} \quad (3)$$

or, more precisely,

Load factor γ $\times$ effect of limit load $Q_T < \text{strength factor } \Phi \times \text{characteristic strength } R_c$.

With the approach proposed, system limit loads Q_T are used for design without additional load factors. Consequently, γ is taken equal to 1.

Thus the previous relation becomes:

$$\text{effect of } Q_T < \Phi \times R_c \quad (4)$$

For weather related loads, the effects of Q_T are detailed in 6.2 to 6.4.

Formula (5) is used to compute the minimum value of characteristic strength R_c for each component in order to withstand limit loads.

$$R_c > (\text{effect of } Q_T) / \Phi \quad (5)$$

Limit load Q_T can be obtained from the statistical analysis of climatic data in accordance with techniques detailed in Annexes C and D. In some national standards, a reference (usually a 50 year return period value) climatic variable is specified. In such a case, the climatic variable for any return period T (years) can be estimated by multiplying the 50 year reference value of the climatic variable by the load factor γ_T , given in Table 2. In case other types of distribution functions are found to better represent the variation of yearly extreme values, the γ_T factors below may change.

Table 2 – Default γ_T factors for adjustment of climatic loads in relation to return period T versus 50 years

Return period T years	Wind speed	Ice variable		
	γ_{TW}	γ_{Tit} (ice thickness)	or	γ_{TIW} (ice weight)
50	1	1		1
150	1,10	1,15		1,20
500	1,20	1,30		1,45

NOTE The above γ values are sufficiently accurate for a COV of up to 16 % for wind speed, 30 % for ice thickness and 65 % for unit ice weight and are derived from the Gumbel distribution function.

5.2.2 Design requirements for the system

Three types of design conditions shall be checked: reliability, security and safety. Table 3 summarizes the context of loads, the required performance and the strengths limit states associated with each condition.

Table 3 – Design requirements for the system

Condition (or requirement)	Type of load	Required performance	Corresponding limit state
Reliability	Climatic loads due to wind, ice, ice plus wind, and temperature, having a return period T	To ensure reliable and safe power transmission capability	Damage limit
Security	Torsional, vertical, and longitudinal loads	To reduce the probability of uncontrollable propagation of failures (failure containment)	Failure limit
Safety	Construction and maintenance loads	To ensure safe construction and maintenance conditions	Damage limit

5.2.3 Design formula for each component

When designing individual line components, Formula (4) can be expanded into:

$$\gamma_U \times \text{effect of } Q_T < \Phi_R \times R_C \quad (6)$$

γ_U is the use factor coefficient. It is derived from the distribution function of the use factor U and expresses the relationship between effective (actual) and design (original) conditions or parameters. The use factor U is a random variable equal to the ratio of the effective (actual line conditions) limit load applied to a component by a climatic event to the design limit load for this component under the same climatic event (using maximum parameters). Symbol γ_U is introduced because components are designed in general by families, not individually for each support and location. Thus, since components are usually designed prior to specific knowledge of their real line parameters (wind and weight spans and angle of deviation), it is admissible to use $\gamma_U = 1$ for new lines design.

NOTE This is equivalent to considering that design is controlled by the maximum span in the line for a given support type.

It is important to note this simplification will certainly have a positive influence on reliability. However, the influence of γ_U on reliability can be fully considered for existing lines, where use parameters of components are fully known. For a detailed discussion on the subject, refer to Annex E.

R_C is the characteristic strength. It is the value guaranteed in appropriate standards for new components, usually with a 90 % to 98 % probability. This value is also called the guaranteed strength, the minimum strength or the minimum failing load. When not specified or calculated, the exclusion limit of R_C can be conservatively taken as 10 % (typical values are in the range of 2 % to 10 %). It is generally accepted that line components will age with time, just like any structural components, and will suffer a reduction in their strength. This quantification of loss of strength with time is not covered in this standard and the reliability values suggested herein are based on new line conditions. If the reduction of strength due to ageing or fatigue can be quantified in some components, it is needed to define the minimum residual strength that should trigger the replacement of these components.

Very often, standards only provide a single normative value usually associated with failure of the component, while the design approach mentioned above requires the consideration of two limits: damage and failure limits. If the damage limit corresponding to R_C is not specified in the standards, Tables 18 to 21 can be used to provide such values.

Φ_R is a global strength factor applicable to the component being designed that takes into account:

- a) features related to the system
 - the number (N) of components exposed to the limit load Q_T during any single occurrence of this load event, (hence Φ_N);
 - the coordination of strengths selected between components, (hence Φ_S).
- b) features related to the component
 - the difference in the quality of the component during prototype testing and actual installation, (hence Φ_Q);
 - the difference between the actual exclusion limit of R_c and the supposed $e = 10\%$, (hence Φ_c).

As these factors are assumed statistically independent:

$$\Phi_R = \Phi_N \times \Phi_S \times \Phi_Q \times \Phi_c \quad (7)$$

The above strength factors Φ are detailed in 7.2.

6 Loadings

6.1 Description

This clause defines structural loadings considered for the design of transmission line components.

As indicated in 5.2.1, three load categories are considered:

- a) loads due to climatic events or any loads derived from them which govern the reliability of the line for the expected life time.

These loads will be analysed in the following subclauses:

- wind loads (6.2);
- ice without wind (6.3);
- ice with wind (6.4);
- b) loads related to safety requirements (construction and maintenance) (6.5);
- c) loads related to security requirements (failure containment) (6.6).

6.2 Climatic loads, wind and associated temperatures

6.2.1 General

This subclause defines the procedures to evaluate the wind and associated temperature effects on line components and elements (conductors, insulator strings, supports).

6.2.2 Field of application

Although this subclause applies in principle to any overhead line, it is most accurately defined for the following conditions:

- Span lengths between 200 m and 800 m. Calculations of the various coefficients (in particular for gusty winds) have to be checked for span lengths outside this range. However, for span lengths greater than 800 m, a gust coefficient corresponding to 800 m span could be safely chosen. For span lengths less than 200 m, the values applicable to 200 m span can be applied.

- Height of supports less than 60 m. Taller supports could be designed following the same principles, but the calculated wind actions would need to be checked. In particular, the eigen frequency of structures above 60 m will often increase the gust response factor.
- Altitude of crossed areas not exceeding 1 300 m above the average level of the topographic environment, except where specific study results are available.
- Terrain without local topographical features whose size and shape are likely to significantly affect the wind profile of the region under consideration.

It is important to note that requirements for special winds associated with localized events such as tornadoes are not part of the normative requirements in this standard. It is however recognized that these winds can cause serious damage to transmission lines either directly (due to wind forces) or indirectly (due to impact of debris carried by wind)². Furthermore, the effects of acceleration due to funnelling between hills are not covered and may require specific climatic studies to assess such influences. In the informative Annex G, proposals are made to deal with wind acceleration due to local topography such as slopes.

6.2.3 Terrain roughness

Wind speed and turbulence depend on the terrain roughness. With increasing terrain roughness, turbulence increases and wind speed decreases near ground level. Four types of terrain categories, with increasing roughness values, are considered in this standard as indicated in Table 4.

Table 4 – Classification of terrain categories

Terrain category	Roughness characteristics
A	Large stretch of water upwind, flat coastal areas
B	Open country with very few obstacles, for example airports or cultivated fields with few trees or buildings
C	Terrain with numerous small obstacles of low height (hedges, trees and buildings)
D	Suburban areas or terrain with many tall trees

It is noted that snow accumulation on the ground will reduce the ground roughness and may increase the terrain category to a higher one in Table 4. However, this should also take into account the duration of such snow and the occurrence of very high wind speeds during snow presence

In areas where trees could be cut, care should be taken in the selection of the terrain category.

6.2.4 Reference wind speed V_R

The reference wind speed V_R (m/s) corresponding to the selected return period T is defined as mean value of the wind during a 10 min period at a level of 10 m above ground.

Usually V_R is measured in weather stations typical of terrain type B. In such cases, V_R is identified as V_{RB} .

² CIGRE WG B2.06 has published Technical Brochure No. 350 on special localized high intensity wind phenomena such as tornadoes and downbursts. The proposals of this Brochure will benefit from validation by service experience and are referred to in order to encourage additional research and comprehension about the impact of HIW on overhead transmission lines. These studies suggest some simplified support load cases that could reduce the probability of failure of structures subjected to such wind events. It is however important to note that many of these high wind events involve flying debris that can lead to support failures irrespective of the proposed strengthening.

If the reference wind speed for terrain category B, V_{RB} is only known, V_R can be determined with

$$V_R = K_R V_{RB} \quad (8)$$

where K_R is the roughness factor in Table 5.

When available wind data differs from these assumptions, refer to 6.2.5 for conversion methods.

6.2.5 Assessment of meteorological measurements

Wind action is evaluated on the basis of the reference wind speed V_R that can be determined from a statistical analysis of relevant wind speed data at 10 m above ground and with an averaging period of 10 min.

Usually, meteorological stations (except those along the coast or in urban areas) are placed in areas of B terrain category, such as airports.

Nevertheless, the meteorological wind speed may be recorded in a terrain category $\times$ site at 10 m above the ground as a mean value over a period of time t in s. Let $V_{x,t}$ be this speed. If it is not measured at 10 m height above ground, the data should be adjusted first to this reference height of 10 m.

The variation of V in terms of height was not taken into account, as anemometers are, most of the time, placed at a height of about 10 m above surrounding ground. If this height z (m) differs from 10 m, the variation of wind speed with height z can be derived from the so-called “power law”, shown in Formula (9). The value of α is found in Table 5.

Table 5 – Factors describing wind action depending on terrain category

Factor	Terrain category			
	A	B	C	D
α	0,10 to 0,12	0,16	0,22	0,28
K_R	1,08	1,00	0,85	0,67

$$V_z = V_R \left(\frac{z}{10} \right)^\alpha \quad (9)$$

Or more generally:

$$V_{z1} = V_{z2} \left(\frac{z1}{z2} \right)^\alpha \quad (10)$$

The curves of Figure 3 enable to determine the ratio $V_{x,t} / V_{x,10 \text{ min}}$ as a function of the averaging period for each category of roughness at the location of the meteorological site. These values may be used in the absence of local data or studies.

NOTE Some countries have recently switched to a 2 s or 3 s averaging period. The conversion from the 2 s or 3 s wind speeds to the 10 min wind can be derived from available wind statistics, or if lacking, from Figure 3.