

Guide to

Loading and strength of overhead transmission lines

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Power Electrical Engineering Standards Policy Committee (PEL/-) to Technical Committee PEL/17, upon which the following bodies were represented:

- Aluminium Federation
- Association of Consulting Engineers
- BECCAMA (BEAMA Electrical Cable Conductor Accessory Manufacturers' Association)
- British Non-Ferrous Metals Federation
- British Railways Board
- Department of Trade and Industry (Electricity Division)
- Electrical and Electronic Insulation Association (BEAMA Ltd.)
- Electricity Association
- Overhead Transmission Line Contractors (BEAMA Ltd.)

This British Standard, having been prepared under the direction of the Power Electrical Engineering Standards Policy Committee, was published under the authority of the Standards Board and comes into effect on 15 April 1994

© BSI 10-1999

The following BSI references relate to the work on this standard:
Committee reference PEL/17
Draft for comment 87/29345 DC

ISBN 0 580 22818 5

Amendments issued since publication

Amd. No.	Date	Comments

Contents

	Page
Committees responsible	Inside front cover
National foreword	iv
Introduction	1
Section 1. General	
1.1 Scope	2
1.2 Definitions	2
1.3 Symbols and abbreviations	3
1.4 Design basis	6
1.5 System design	6
1.6 Assessment of line reliability	7
1.7 Security requirements	12
1.8 Safety requirements	12
Section 2. Design criteria	
2.1 General	12
2.2 Design criteria	15
2.3 Design criteria for towers	18
2.4 Design criteria for foundations	18
2.5 Design criteria for conductors and earth wires	19
2.6 Design criteria for insulators and hardware	19
Section 3. Loadings	
3.1 General	19
3.2 Climatic loads, wind	19
3.3 Climatic loads, ice without wind	31
3.4 Climatic loads, combined wind and ice loadings	38
3.5 Loads for construction and maintenance	44
3.6 Loads for failure containment	46
Section 4. Strength of components and limit states	
4.1 General	47
4.2 Components of transmission line systems	48
4.3 Limit states of line components	48
4.4 Strength data of line components	48
Section 5. Technical justifications	
5.1 Scope	53
5.2 Relation between load and strength	53
5.3 Effect of span dispersion on reliability	57
5.4 Strength coordination of line components	57
5.5 Number of components subjected to maximum load intensity	59
Annex A (informative) The effect of span dispersion on load-strength relationship: calculation of span use factor	61
Annex B (informative) The Beta distribution function	65
Annex C (informative) Statistical distribution of maximum yearly wind velocity and ice load	66
Annex D (informative) Characteristic strength of components	68
Annex E (informative) Determination of the meteorological reference wind velocity	70
Annex F (informative) Gradient wind speeds	71
Annex G (informative) Temperature measurements and their interpretation	71
Annex H (informative) Types of icing	72

	Page
Annex J (informative) Atmospheric icing process and terrain influences	73
Annex K (informative) Guidelines for the implementation of an ice observation programme	74
Figure 1 — Relations between load and strength	8
Figure 2 — Methodology for the design of transmission lines	14
Figure 3 — Ground roughness A	25
Figure 4 — Ground roughness B	25
Figure 5 — Ground roughness C	26
Figure 6 — Ground roughness D	26
Figure 7 — Determination of the apparent length of $2 L_m$ of the two adjacent spans on the considered support	27
Figure 8 — Gust factor of insulators and towers: G_i , G_t	28
Figure 9 — Definition of the solidity ratio	29
Figure 10 — Overall normal drag coefficients for rectangular towers composed of flat-sided members C_{xT}	29
Figure 11 — Overall normal drag coefficients for rectangular towers composed of circular section members C_{xT}	30
Figure 12 — Value of C_{xTc} drag coefficient of cylindrical elements having a large diameter, as a function of Reynolds number R_e	31
Figure 13 — Factor related to the influence of the number of years of observation of ice	33
Figure 14 — Factor related to the influence of conductor diameter	34
Figure 15 — Variation of K_h with the height of conductors above the ground	34
Figure 16	36
Figure 17	37
Figure 18 — Cases of combined ice-wind loadings given as an indication	39
Figure 19 — Factor related to the influence of the number of years with observation of wind combined with ice	41
Figure 20 — Definition of cylindrical ice shape	42
Figure 21 — Application of longitudinal loads	45
Figure 22	46
Figure 23	47
Figure 24 — Diagram of transmission line system	48
Figure 25 — Diagram of a transmission line diagram	49
Figure 26 — Values of $P_f = (1 - P_s)$ for various distributions of Q and R for $T = 50$ years	55
Figure 27 — Values of $P_f = (1 - P_s)$ for various distributions of Q and R for $T = 150$ years	56
Figure 28 — Values of $P_f = (1 - P_s)$ for various distributions of Q and R for $T = 500$ years	56
Figure B.1 — Different forms of the Beta distribution	66
Figure E.1 — Relationship between meteorological wind velocities at a height of 10 m	71
Figure K.1	75
Table 1 — Typical strength coordination	7
Table 2 — Reliability corresponding to various assumptions of load and strength	11
Table 3 — Relationship between reliability levels and return periods of design loads	11

	Page
Table 4 — Reliability levels of transmission lines	13
Table 5 — Design conditions	15
Table 6 — Range of spatial coverage of maximum load intensity (given in number of towers)	17
Table 7 — Number of towers subjected to maximum load intensity	17
Table 8 — Strength factor ϕ_N related to the number N of components subjected to the critical load intensity	17
Table 9 — Values of ϕ_S	18
Table 10 — Definition of ground roughness	20
Table 11 — Values of high wind velocity	21
Table 12 — Values of K_R for different ground roughness	21
Table 13 — Statistical parameters of ice loads	32
Table 14 — Values of ice load coefficient K_{og}	33
Table 15 — Return period of combined events	38
Table 16 — Combined wind and ice loading conditions	39
Table 17 — Values of K_{oL} and K_{oH}	40
Table 18 — Values of factors K_{iH} and K_{iL}	40
Table 19 — Drag coefficients of ice-covered conductors	42
Table 20 — Damage and failure limits of supports	50
Table 21 — Damage and failure limits of foundations	51
Table 22 — Damage and failure limits of conductors and ground wires	52
Table 23 — Damage and failure limits of interface components	52
Table 24 — Strength parameters of supports	52
Table 25 — Strength parameters of foundations (in uplift)	53
Table 26 — Strength parameters of interface components	53
Table 27 — Strength parameters of conductors and ground wires	53
Table 28 — Values of ratio of average strengths (RAS) and ϕ_S required to insure that component R_2 will fail after component R_1 with a 90 % probability	59
Table 29 — Strength coefficient ϕ_N related to N components in series subjected to the critical load	60
Table A.1 — Statistical parameters of wind span variation	62
Table A.2 — Statistical parameters of weight span variation	62
Table A.3 — Values of γ_u as a function of U and N for $v_R = 10$ %	63
Table A.4 — Values of γ_u for different strength dispersions	64
Table C.1 — Values of the constants C_1 and C_2	66
Table C.2 — Probability of exceeding an event having a return period T	67
Table C.3 — Ratios of $x/\bar{x}$ for an extreme type 1	68
Table D.1 — Values of K_c	69
Table D.2 — Value of quality factor ϕ_Q for lattice towers	69
Table E.1 — Values of factor K_j	70
Table H.1 — Physical properties of ice	72
Table H.2 — Meteorological parameters controlling ice accretion	72
List of references	Inside back cover

National foreword

This British Standard has been prepared under the direction of the Power Electrical Engineering Standards Policy Committee. It is identical with IEC 826:1991 *Loading and strength of overhead transmission lines*, incorporating Corrigendum September 1991, published by the International Electrotechnical Commission (IEC).

This British Standard was approved for publication in November 1993 as a guide to what should be considered in determining the loading and strength of overhead transmission lines.

Cross-references

IEC 652:1979	BS 7732:1994 <i>Guide to the loading tests on overhead line towers</i> (Identical)
--------------	---

The Technical Committee has reviewed the provisions of IEC 383, to which informative reference is made in the text, and has decided that they are acceptable for use in conjunction with this standard. A related standard to IEC 383 is BS 137-1:1982.

The graphic signs, symbols and letters used in this standard may be found in:

BS 3939	<i>Graphic symbols for electrical power, telecommunications and electronics diagrams</i>
Part 1:1986	<i>General information, general index</i>
Part 2:1985	<i>Symbol elements, qualifying symbols and other symbols having general application</i>

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 76, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Introduction

Probabilistic methods are recommended for the design of transmission lines as opposed to deterministic methods because they openly acknowledge that in practice there is always some risk that design loads can be exceeded and as a result complete reliability cannot be achieved.

The proposed methods also provide for designing according to different levels of reliability depending on either the importance of lines in the system, or on varying requirements for public safety.

The techniques described enable the designer to assess the reliabilities of existing lines or to design new lines for target reliabilities provided that the data required for such analysis are available.

However, it is recognized that for many locations and situations much of the data may not be available to the extent necessary for confidence in the calculation of absolute reliability.

In such cases the recommended methods will be effective for estimating the relative reliabilities of different designs. It will be noted that the alternative to designing to target reliabilities ends up as one of designing for varying return periods of climatic events, specifically 50, 150 and 500 years. It is considered that these represent reasonable differences between reliability levels, although different return periods may be selected if desired.

The actual reliability of lines is sensitive to the accuracy of many design parameters. Some of the typical parameters which may affect reliability are discussed hereafter.

Although the basic formula for calculating wind loads from measured velocities is well known, it requires the use of a number of coefficients that are not precise. For instance drag coefficients for conductors and bundles depend on conductor stranding and bundle configuration. It is not possible to give an absolute recommendation covering all conductors in all situations in a report such as this, and the best that can be achieved represents some sort of compromise.

Similarly, the effects of varying terrain are not exact and inaccuracies in selecting the appropriate coefficient may lead to differences as large as that separating reliability levels. The estimation of wind speeds between widely-spaced measuring situations is likely to be inexact and can lead to unpredictable errors in load calculations.

Data on ice loads and wind-on-ice are sparse and the recommendations given in this report are based on the judgement of knowledgeable and experienced engineers and scientists. But for many situations they will be only broad approximations.

Similar comments may be made with respect to the strength of line components, although in general they are more precisely known than climatic loads with the exception of foundations. The use factors of these components (the percentage of their rated strength that is used to carry loads) may not be known and can affect reliability.

Although the report does propose a method for estimating use factor, there is room for error which in general should be on the side of safety.

The above discussion does not represent a complete catalogue of all grounds for uncertainties but does indicate the type of analysis that the designer shall go through in order to design for target reliabilities with confidence. Having done this and if the designer is satisfied with the completeness and accuracy of the data for the particular situation, the report may be used as originally intended, i.e., providing for a reliability based design of transmission lines.

Notwithstanding the uncertainties of the existing probabilistic methods, it shall be pointed out that deterministic methods have many of the same pitfalls that are generally not acknowledged. The approach recommended in this report provides a consistent and logical way of relating loads and strengths, and will result in economic and safe transmission lines whenever the required data is available.

Finally, it is important to compare the results obtained by the proposed methods with existing ones which have proved to be satisfactory. This comparison should allow further adjustment of some of the proposed factors according to local experience.

Section 1. General

1.1 Scope

This report applies to overhead lines of nominal voltage above 45 kV. It may also be applied to lines with a lower nominal voltage.

The purpose of this report is to propose relationships between loads imposed on transmission lines and the strengths of transmission line components in order to obtain safe and economical designs.

This report also provides a framework for the preparation of national standards dealing with design of overhead transmission lines based on probabilistic or semi-probabilistic methods.

1.2 Definitions

1.2.1

characteristic strength (R_c)

the value guaranteed in appropriate standards. This value is also called the guaranteed strength, the minimum strength, the minimum failing load or the nominal strength, and usually corresponds to an exclusion limit, from 2 % to 5 %, with 10 % being, in practice, the upper limit

1.2.2

coefficient of variation (COV) or dispersion

the ratio of the standard deviation to the mean value. The COV of strength and load are respectively denoted by v_R and v_Q

1.2.3

components

group of elements having a specified task in the transmission line system. Typical components are towers, foundations, conductors, insulator strings and hardware

1.2.4

damage limit (of a component)

the strength limit of a component which leads to damage to the system if it is exceeded

1.2.5

damage state

the state where the system has to be repaired because it is not capable of fulfilling its task under design loads or because design clearances may be reduced (e.g. conductor to ground)

1.2.6

elements

different parts of a component. For example, the elements of a steel lattice tower are steel angles, plates and bolts

1.2.7

exclusion limit (e %) of a variable

the value of a variable taken from its distribution function and corresponding to a probability of e % of not being exceeded

1.2.8

failure limit (of a component)

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

1.2.9

failure state

the state of a system in which a major component has failed by rupture, buckling, overturning, etc., thus leading to the termination of the ability of the line to transmit power

1.2.10

intact state

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

1.2.11**operating period**

general measure of useful life. Typical operating periods of transmission lines vary from 30 to 80 years

1.2.12**return period (of a climatic event)**

the mean interval between recurrences of a climatic event of defined magnitude. The inverse of the return period gives the probability of exceeding the event in one year

1.2.13**reliability (structural)**

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

1.2.14**security (structural)**

the ability of a system to be protected from a major collapse (cascading effect) if a failure is triggered in a given component. Security is a deterministic concept as opposed to reliability which is a probabilistic concept

1.2.15**safety**

the ability of a system not to cause human injuries or loss of lives. In this report, safety relates mainly to protection of workers during construction and maintenance operations. The safety of public and environment in general is covered by national regulations

1.2.16**strength factor (ϕ)**

a coefficient applied to the limit stresses of a component. This factor takes into account the coordination of strength, the number of components subjected to maximum load, quality and statistical parameters of components

1.2.17**system**

a set of components connected together to form the transmission line

1.2.18**task**

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

1.2.19**unavailability**

the inability of a system to accomplish its task. Unavailability of transmission lines results from structural unreliability as well as from failure due to other casual events such as landslides, impact of objects, sabotage, defects in material, etc.

1.2.20**use factor (γ_u)**

the ratio of stresses due to design load and the stress limit of a component. For tangent towers, it is virtually equal to the ratio of actual to maximum design spans (wind or weight) and for angle towers, it also includes the ratio of the sines of the half angles of deviation (actual to design angles)

1.3 Symbols and abbreviations

a = Unit action of wind on line elements.

A_c = Wind forces on conductors.

A_i = Wind forces on insulators.

A_t = Wind forces acting on a tower panel (A_{tc} on cylindrical tower members).

B	=	Horizontal distance between foundations of a support.
B_i	=	Reduction factor of the maximum yearly wind velocities.
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_{xT1} C_{xT2} C_{xT3}	}	Drag coefficient of supports
COV	=	Coefficient of variation, also identified as v_x .
d	=	Conductor diameter.
d_t	=	Diameter of cylindrical tower elements.
D	=	Equivalent diameter of ice covered conductors (D_H for high probability and D_L for low probability).
e	=	Exclusion probability in %.
e_N	=	Exclusion probability of N components in series in %.
f_x	=	Density function of variable x .
F_x	=	Cumulative probability function of x .
F_N	=	Normal Gaussian cumulative probability function.
G_c	=	Combined wind factor of conductors.
G_t	=	Combined wind factor of towers.
G_i	=	Combined wind factor of insulators.
g	=	Yearly maximum ice loads.
$\bar{g}$	=	Mean value of yearly maximum ice load.
$g_{\max}$	=	Maximum observed ice load.
g_R	=	Reference design ice load.
g_H	=	Ice load having a high probability.
g_L	=	Ice load having a low probability.
h	=	Height of panel in a lattice tower.
K_c	=	Number of standard deviations between average and characteristic strength.
K_R	=	Roughness coefficient.
K_d	=	Factor related to the influence of conductor diameter.
K_G	=	Factor related to gradient wind speed.
K_h	=	Factor related to the influence of height above ground.
K_n	=	Factor related to the influence of the number of years with observation.
$K_{\sigma g}$ $K_{\sigma L}$ $K_{\sigma H}$	}	Factors applied to the average ice load for calculation of combined loads.
K_{iL} K_{iH}	}	Factors applied to wind speed V_{em} for calculation of combined load.
K_j	=	Factor related to the influence of the roughness of the location of the meteorological station site.
L	=	Span length.

L_m	=	Average span.
n	=	Number of years of observation of a climatic event.
N	=	Number of components subjected to maximum loading intensity.
P_s	=	Probability of survival.
P_{si}	=	Probability of survival of component i .
Q	=	Load or load effect.
Q_T	=	Load having a return period T .
Q_{Tv}	}	Components of load Q_T , vertical, wind and tension.
Q_{Tw}		
Q_{Tt}		
Q'	=	Load adjusted for the influence of span dispersion.
q_0	=	Dynamic pressure due to reference wind speed V_R .
R	=	Strength.
$\bar{R}$	=	Average strength.
R_c	=	Characteristic strength.
$(e)R$	=	Strength with an exclusion probability of e .
S_i	=	Projected area of insulators.
S_t	=	Projected area of a tower panel.
T	=	Return period of an event in years.
U	=	Use factor.
v_x	=	Coefficient of variation of variable x .
V_m	=	Maximum yearly wind velocity.
V_M	=	High wind velocity.
V_{MG}	=	Gradient wind speed
V_R	=	Reference wind velocity for design.
V_e	=	Wind velocity associated with icing.
V_{em}	=	Maximum wind velocity associated with icing.
V_{iL}	=	Low probability reference wind velocity associated with icing.
V_{iH}	=	High probability reference wind velocity associated with icing.
Z	=	Height above ground of conductors, centre of gravity of tower panels, or insulator strings.
α	=	Reduction factor for unbalanced ice loads.
γ_u	=	Load factor due to span dispersion.
δ_1	}	Ice density.
δ_2		
Γ	=	Gamma function.
Φ	=	Strength factor.
Φ_N	=	Strength factor due to the 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 .
Φ_R	=	Product of Φ_N , Φ_S , Φ_Q , Φ_C .
σ_x	=	Standard deviation of x .
κ	=	Solidity ratio of a tower panel.

μ	=	Density of air per unit volume at the reference temperature and pressure.
Ω	=	Angle of incidence of wind with respect to line axis.
θ	=	Angle of incidence of wind with the tower panel.
θ'	=	Angle of incidence of wind with cylindrical elements of tower.
ω	=	Unit weight of conductor or ground wire.

1.4 Design basis

1.4.1 General

The design criteria recommended in this report are based on probabilistic or semi-probabilistic methods. The introduction gives recommendations on how to use them. Designers shall pay attention to the application of these methods, specially to the choice of the different factors and must be aware of the necessity of sufficient available data.

1.4.2 Line security

Special requirements are prescribed in order to limit secondary failures as well as the consequences of failures due to events that cannot be accounted for in the design process.

1.4.3 Safety

Specific requirements are included in this report in order to assure the safety of people working on the transmission line during construction and maintenance.

These requirements complement other safety considerations prescribed by national standards or regulations.

1.5 System design

1.5.1 Description

This report is based on the concept whereby a transmission line is considered as a system. Thus all reliability or performance values discussed in this report relate to a complete line.

This approach enables the designer to coordinate logically the strengths of components within the system.

A system design approach recognizes the fact that a transmission line is composed of a series of components where the failure of any major component usually leads to the loss of power transmitting capability. It also allows components to be designed with compatible strengths thus leading to an overall economical design without undesirable mismatch.

1.5.2 Simplifications behind a system design approach

The reliability of a system is a function of the reliability of its components. When these components are in series, the reliability or probability of survival of the system (P_{ss}) is equal to the product of the probability of survival of each component (P_{si}):

$$P_{ss} = P_{s1} P_{s2} \dots P_{sn} = \prod_{i=1}^n P_{si} \quad (1)$$

In cases where the reliability of components is greater than $(1 - 10^{-2})$, which is usually the case with typical transmission lines, and one component has a risk of failure or a rate of unreliability, which is by approximately one order of magnitude higher than other components, the reliability of the system can be approximated by that of the least reliable component.

This situation occurs naturally in many transmission lines. For example, in non-icing areas, conductor tension limitations of the every day stress to obviate vibration problems may limit the maximum tension under wind to some 50 % of the rated tensile strength of the conductor. This in turn increases very substantially the probability of survival of conductors as compared to towers. Consequently conductors in non-icing areas properly installed and protected from vibration damage are naturally more reliable than other components.

However, in heavy icing areas, the vibration limit may not be critical and conductors may be equally or even less reliable than towers. In such cases, if it is desired to have conductors more reliable than towers, a coordination of strength between components has to be a design objective.

1.5.3 Coordination of strength of components

In order to decide on an appropriate strength coordination, the following criteria are recommended:

- The first component to fail should be chosen so as to introduce the least secondary load effect (dynamic or static) on other components, in order to minimize cascading failure.
- Repair time and costs following a failure should be kept to a minimum.
- The first component to fail should ideally¹⁾ have a ratio of the damage limit to the failure limit near 1,0.
- A low cost component in series with a high cost component should be designed to be at least as strong and reliable as the major component if the consequences of failure are as severe as failure of that major component²⁾.

If line components such as tangent towers, tension towers, conductors, foundations and hardware are analyzed using the above criteria, it is found that: conductors should not be the weakest component because of a, b and c; hardware because of d; tension towers because of a and b; and foundations because of b and c.

An appropriate strength coordination applying these criteria is given in Table 1, where tangent towers are the first component to fail when the line is subjected to loads exceeding design values.

While these criteria are the result of logical deduction, it is found in practice that, with a few exceptions³⁾, the design of the great majority of existing transmission lines conforms closely with the proposed coordination of strength.

Furthermore, it should be noted, as indicated in 1.5.2, that the coordination of strength also simplifies reliability calculations.

Table 1 — Typical strength coordination

	Major components	Coordination within major components ^a
To fail first	Tangent tower	<u>Tower</u> , foundations, hardware
Not to fail first with 90 % confidence	Angle tower	<u>Tower</u> , foundations, hardware
	Dead end tower	<u>Tower</u> , foundations, hardware
	Conductors	<u>Conductors</u> , insulators, hardware

^a Within each major component the underlined component is the weakest with 90 % confidence.

1.6 Assessment of line reliability

1.6.1 Basic principles

On a theoretical basis, the reliability (probability of survival) of a transmission line can be assessed using the following procedure.

- For each type of climatic load, establish the probability density function of load, f_Q . This function is adjusted to reflect the maximum loading intensity that might occur within the space covered by the line. Any proven directional tendencies which might affect load intensity are also weighted in the load function f_Q , otherwise the load is assumed to act in the most critical direction.
- Establish the strength density function f_R of the line as a system. The function can be complex except when lines are designed with a strength coordination approach (see 1.5.3). In this case, function f_R can be approximated by the strength density function of the weakest component.
- Define the relative position of the two curves f_Q and f_R .

¹⁾ It may be difficult to coordinate the strength of components when the least reliable one has a very large strength dispersion.

²⁾ An exception to this criterion is when a component is purposely designed to act as a load limiting device. In such a case its strength has to be well tuned with the component it is supposed to protect.

³⁾ The above strength coordination can be applied to most lines. However there will be some situations where different criteria could be used and thus lead to another sequence of failure.

For example, special river-crossing towers could be designed stronger than the conductors. In avalanche areas where construction of towers is very difficult, conductors may also be chosen as the weakest component, provided that tangent towers are designed for the forces resulting from the failure of these conductors. Otherwise the failure of conductors will automatically lead to the failure of adjacent towers.

This relative position can be defined through a relation such as: a load with a probability of occurrence $1/T$ is set equal to the strength with a 10 % exclusion limit, or analytically:

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

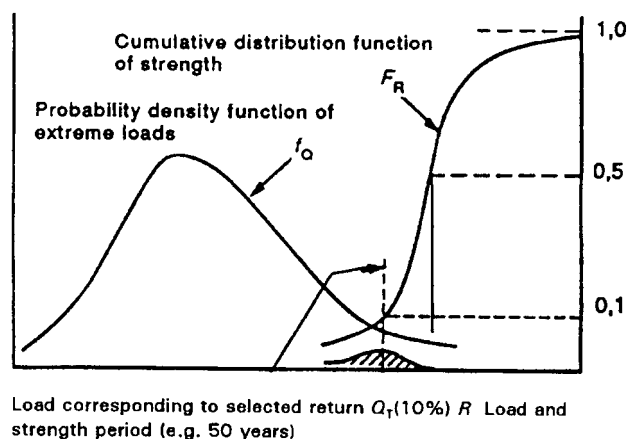


Figure 1 — Relations between load and strength

The choice of the return period T of load depends on the desired degree of reliability.

It can be shown that equation (2) leads to an almost constant reliability of the order of $(1 - 1/2T)$, independent of the shape of the load and strength curves and their dispersions (see 5.2).

In practice, the reliability resulting from the relationship expressed in equation (2), can be considered as a minimum value and calculations can be further refined through the introduction of correction factors related to the following items:

- a) use factors of components: the fact that all components are not used at their maximum design parameter contributes to an increase of the reliability;
- b) relation between the characteristic strength and (10 %) R: the characteristic strength of most components corresponds to an exclusion limit less than 10 %. If it is assumed to be equal to 10 %, the resulting reliability will be higher;
- c) selected strength coordination;
- d) number of components subjected to maximum loading intensity whenever a storm occurs;
- e) quality control during fabrication and construction.

1.6.2 Loadings

Loadings on transmission lines can be separated into three groups: live loads, dead loads and special loads. Calculations related to these loads are given in section 3.

1.6.2.1 Live loads

Live loads are random loads due to wind and ice taken separately or combined together. These can be modelled by appropriate probability density functions.

When statistics of annual maximum values of ice or wind are available, it is commonly accepted that these climatic variables follow an extreme distribution function, usually of type I Gumbel distribution as described in Annex C. This distribution function can be defined with two parameters: the mean value and the standard deviation of the applicable variable.

1.6.2.2 Dead loads

Dead loads are loads due to the dead weight of towers, conductors and hardware. Although they are permanent in nature, dead loads vary from one tower to another due to variation of tower height and weight span of conductors.

Reliability of lines subjected only to dead loads should be practically 100 %. This reliability is provided by the safety requirements where it is specified that towers should be designed for twice the vertical dead load of conductors with hardware (see 3.5.4). These requirements cover the increase in vertical loads during construction and maintenance which occurs during operations on conductors such as: stringing, lifting or lowering.

The weight of conductors supported by towers is the product of weight per unit length, which is practically constant, and the weight span⁴⁾ which may vary according to the tower spacing and elevation and the conductor tension. In all cases, the weight span of a given tower type has a maximum assigned value which is the one considered for the design of towers. (There is also a minimum value for uplift considerations of suspension insulator strings.)

Since all towers of a transmission line are not usually used at their maximum spans, this variation of spans, if neglected, contributes to an increase in reliability. For evaluation purposes the ratio of actual span to maximum span is defined as being the span use factor U .

Recent studies have enabled variable U to be modelled so that its influence in reliability calculations through appropriate correction factors, γ_u , can be applied to tower loads.

In cases where data on use factors are not available or cannot be predicted, the influence of U can be neglected and γ_u is considered equal to 1,0.

In other cases where data on span use factor are available or can be predicted, the methodology appearing in Annex A can be used in order to achieve some line cost reductions.

1.6.2.3 Special loads

Special loads consist of external loads that might occur during line construction and maintenance as well as longitudinal and vertical loads provided as a security measure for the prevention of cascading failures (or the propagation of secondary failures).

Construction and maintenance loads are treated in a deterministic manner and are considered constant. They are established in such a way that their magnitude is never likely to be exceeded under normal construction and maintenance operations. If the magnitude of special loads is such that they are more critical than loadings specified in 1.6.2.1 and 1.6.2.2, overall reliability of the line is altered.

1.6.3 Strength

1.6.3.1 Distribution functions of strength of components

The strength of line components usually follows either a normal or a log-normal distribution. The normal (Gaussian) distribution is appropriate for most ductile materials while the log-normal distribution applies more to brittle materials. With stringent quality control, the distribution function of components may be altered and tends to be a log-normal function. Unless otherwise substantiated by relevant data, the normal distribution can be assumed adequate for most line components.

1.6.3.2 Components in series

When a component is made up of a series of elements, its strength distribution function tends to be an extreme function (minima). With an increasing number of elements in series, both the average and the standard deviation of the strength of the series are reduced and the resulting distribution function tends to be an extreme distribution even if the original component is normal.

The statistical parameters of the strength of a series of N components can be derived from available statistical methods.

A description of these methods and a derivation of the correction factor Φ_N due to the number of components subjected to maximum load intensity is given in section 5.

1.6.3.3 Characteristic strength R_c

In order to establish the characteristic strength, two cases are considered: whether or not specific tests are performed on the components or elements of the line.

- a) Without tests

⁴⁾ Graphically, the weight span can be represented by the horizontal distance between the lowest points of the catenaries of adjacent spans.

Most components are specified in national standards using nominal, minimum or guaranteed strength. This is also the case for towers designed with an approved method of calculation based on the minimum mechanical characteristics of the elements.

The strength of a component is usually set so that these minimum requirements are met by the majority of the components. Recent studies, as well as the analysis of a large number of test results, indicate that the probability of line components not meeting the specified strength (exclusion limit) is usually between 1 % and 10 %.

Consequently, whenever the specified strength of a component, without reference to its exclusion limit e , is taken as the characteristic strength, the assumption of $e = 10 \%$ for this component leads to higher reliability.

b) With tests

Whenever tests are performed to determine the strength of a component, the characteristic strength can be obtained from the test results after having calculated $\bar{R}$ and v_R .

Assuming a Gaussian distribution for the strength, then a 10 % probability corresponds to a value of 1,28 standard deviations⁵⁾ below the average:

$$\text{if} \quad R_c = (10 \%) R \quad (3)$$

$$\text{then} \quad R_c = \bar{R} (1 - 1,28 v_R) \quad (4)$$

1.6.4 Calculation of reliability

1.6.4.1 Combinations of load and strength

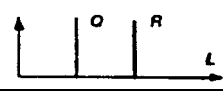
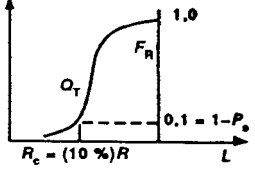
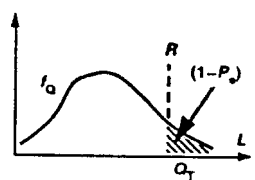
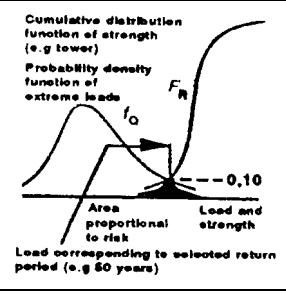
Reliability depends on the parameters of load Q and strength R . In order to illustrate possible combinations, four cases are considered, each one corresponding to different assumptions:

- a) load (Q) and strength (R) have constant values;
- b) load (Q) is constant and strength (R) is variable;
- c) load (Q) is variable and strength (R) is constant;
- d) load (Q) and strength (R) are variables (obviously the most general case and typical of transmission lines).

The values of reliability for these cases are summarized in Table 2.

⁵⁾ The value of 1,28 assumes an infinite number of samples. For reduced number of samples, other values are under consideration.

Table 2 — Reliability corresponding to various assumptions of load and strength

Load Q			Strength R			Reliability P_s^c	
Mean value	COV	Design strength $(e)R^b$	Mean value	COV	Design strength $(e)R^b$	Graphical representation	Results ^d
Q constant	0	Q	R constant	0	R		$P_s = 1,0$
Q constant	0	Q	$\bar{R}$	v_R	$\bar{R}(1 - K_c v_R)$		$P_s = 1 - \int_{-\infty}^{R_c} f_R dL$ $= 1 - F_R$ $= 0,90 \text{ (for } K_c = 1,28)$
$\bar{Q}$	v_Q (20 % to 50 %)	Q_T	R constant	0	R		$P_s = 1 - \int_{Q_T}^{+\infty} f_Q dL$ $= 1 - \frac{1}{T}$
$\bar{Q}$	v_Q (20 % to 50 %)	Q_T	$\bar{R}$	v_R (5 % to 20 %)	$\bar{R}(1 - K_c v_R)$		$P_s = 1 - \int_{-\infty}^{+\infty} f_Q F_R dL$ $= 1 - \frac{1}{2T}$

^a Q_T is the load with a return period T .
^b $(e)R$ is the strength corresponding to an exclusion limit of e .
^c P_s is the probability $Q < R$.
^d In these examples the reliability is given for $e = 10\%$ (where $K_c = 1,28$).

1.6.4.2 Reliability levels

Lines which are designed according to the methodology proposed in this report, have a minimum yearly reliability $P_s = (1 - 1/2T)$. In this case the return period of design loads is equal to $T = 1/[2(1 - P_s)]$

Table 3 gives values of T and P_s corresponding to the most common reliability levels.

Table 3 — Relationship between reliability levels and return periods of design loads

P_s (yearly reliability)	$1 - 10^{-2}$	$1 - 10^{-2,5}$	$1 - 10^{-3}$
T (return period in years)	50	150	500

In Annex C, probabilities of exceeding a weather event Q_T are given. It is however important to recognize that exceeding a design load does not necessarily lead to a loss of reliability because the latter is a combination of an extreme load event occurring on a component unable to resist its effect. This explains the discrepancy between the probability of failure and that of exceeding a load event.

Designers can choose their reliability levels either by calibration with existing lines that have had a long history of satisfactory performance or by optimization methods found in technical literature.

In section 2, guidelines are proposed to help choose the reliability level in the case of unavailability of either of the above techniques.

1.7 Security requirements

1.7.1 Typical security requirements (or measures)

The design methods proposed in this report provide transmission lines with an acceptable reliability in regard to specified climatic events.

However, other events such as impact of objects, avalanches, sabotage, etc., could also affect the performance of lines.

In such cases preventive measures of a deterministic nature, herein called security requirements, can be considered in order to increase the security of the line.

The objective of security measures is to reduce secondary failures and to stop cascading failures that can extend well beyond a failed section. In cases where exceptional external loads in excess of the strength of the line cause a widespread failure, these measures help in preventing the progression of the failure to sections that have a sufficient reserve. Increased security can be achieved by adding strength to some components. As an example, one common security measure for tangent towers involves the specification of longitudinal loads due to release of the conductor tension of one phase under every day conditions, i.e. normal. Another example is the insertion, at a given interval (typically 5 km to 10 km), of strong towers called anti-cascading towers. These towers can be designed to withstand loads due to the tension release of all conductors under ice or wind conditions.

Load limiting devices such as slip clamps, swinging crossarms, shear bolts, etc. have also been used as security measures in order to decrease the risk of failure propagation. However, care should be taken to ensure that these devices would not fail first under reliability related loads and thus be the cause of line failure.

1.7.2 Relation between security and reliability

Even if reliability and security are basically different concepts (probabilistic versus deterministic), it may happen that increasing reliability also increases security. For example, if square based towers are used as a consequence of design requirements, an increase in transverse wind or combined ice and wind loadings generally leads to an increase in longitudinal strength, hence, an increase in security.

The coordination of strength can also be considered as a security measure. For example, if the weakest component is the tangent tower, it will lead to the least load effect (dynamic or static) in case of failure. Thus, lines designed with tangent towers being the weakest component are better protected from cascading failures than lines designed with conductors or angle towers as the weakest component.

1.7.3 Security levels

Lines can be designed for different security levels. Minimum security requirements are given in 3.6. Designers will also have the option of increasing the security by selecting any combination of measures or loadings listed in the same section.

1.8 Safety requirements

In this report specific design requirements are provided in order to ensure safety during construction, maintenance and service. These are called safety requirements.

Consequently, all components subjected to significant loadings during construction and maintenance should be designed with an adequate safety margin to cover such operations. The first step is thus to identify these overloads and their probable maximum intensity, then to design components in such a way that the resulting reliability is practically 1,0 under these load intensities.

Construction and maintenance loads which are specified in this report will complement the safety requirements of national standards for the design of transmission lines.

Section 2. Design criteria

2.1 General

2.1.1 Methodology

The recommended methodology for designing transmission lines is summarized in Figure 2.

This methodology can be described in the following steps:

- a) select the reliability level in terms of return period of design load;

- b) calculate climatic variables corresponding to selected return;
- c) calculate climatic loadings on components. These are called limit loads;
- d) calculate loads corresponding to security requirements (failure containment);
- e) calculate loads related to safety during construction and maintenance;
- f) determine the desired strength coordination;
- g) select appropriate correction factors, if applicable, to the design of components such as use factor, strength factors related to number of components, strength coordination, quality control, and the characteristic strength;
- h) design components for the above loads and strength requirements.

2.1.2 Reliability levels

2.1.2.1 Description

Transmission lines can be designed for different reliability levels (or classes) depending on local requirements.

Three reliability levels are proposed in this report 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 design loads as shown in Table 4.

Table 4 — Reliability levels^a of transmission lines

	Reliability levels		
	I	II	III
<i>T</i> , return period of design loads, in years	50	150	500
^a Whenever loads having a return period <i>T</i> are associated with a strength being exceeded with 90 % probability (exclusion limit 10 %), it is expected that the minimum yearly reliability will be to the order of $(1 - 1/2 T)$ and will be sensitive to the accuracy of prediction of load and strength (availability of data).			

2.1.2.2 Guideline criteria for selection of reliability levels

Reliability levels of transmission lines can be selected by comparison with existing lines that have had a satisfactory performance or with the guidelines subsequently described.

In all cases, lines shall at least meet the requirements of reliability level one.

An increase in reliability above level one could be justified for more important lines of the network as indicated in the following guidelines:

Level two applies mainly to lines above 230 kV⁶⁾ and to lines below 230 kV which constitute the principal or perhaps the only source of supply to a particular load.

Level three applies mainly to lines above 230 kV⁶⁾ which constitute the principal or perhaps the only source of supply to a particular load.

2.1.3 Security requirements

2.1.3.1 Description

Security requirements are provided for transmission lines and correspond to special load and/or measures intended to prevent uncontrollable progressive (or cascading) failures.

2.1.3.2 Minimum security requirements

Should a line fail either due to material defects, casual events (e.g. impact of objects, landslide, etc.) or climatic overload, it is essential that the failure be contained within or very close to the section where overloads exceeding the strengths of components have occurred.

In order to prevent cascading failures, some simulated tower loading conditions (longitudinal and torsional) are provided as described in 3.6 of section 3. These loads should provide for adequate protection against cascading failures for the majority of transmission lines using lattice towers.

⁶⁾ The voltage level of 230 kV may vary in different countries according to the importance of the line, on the network.

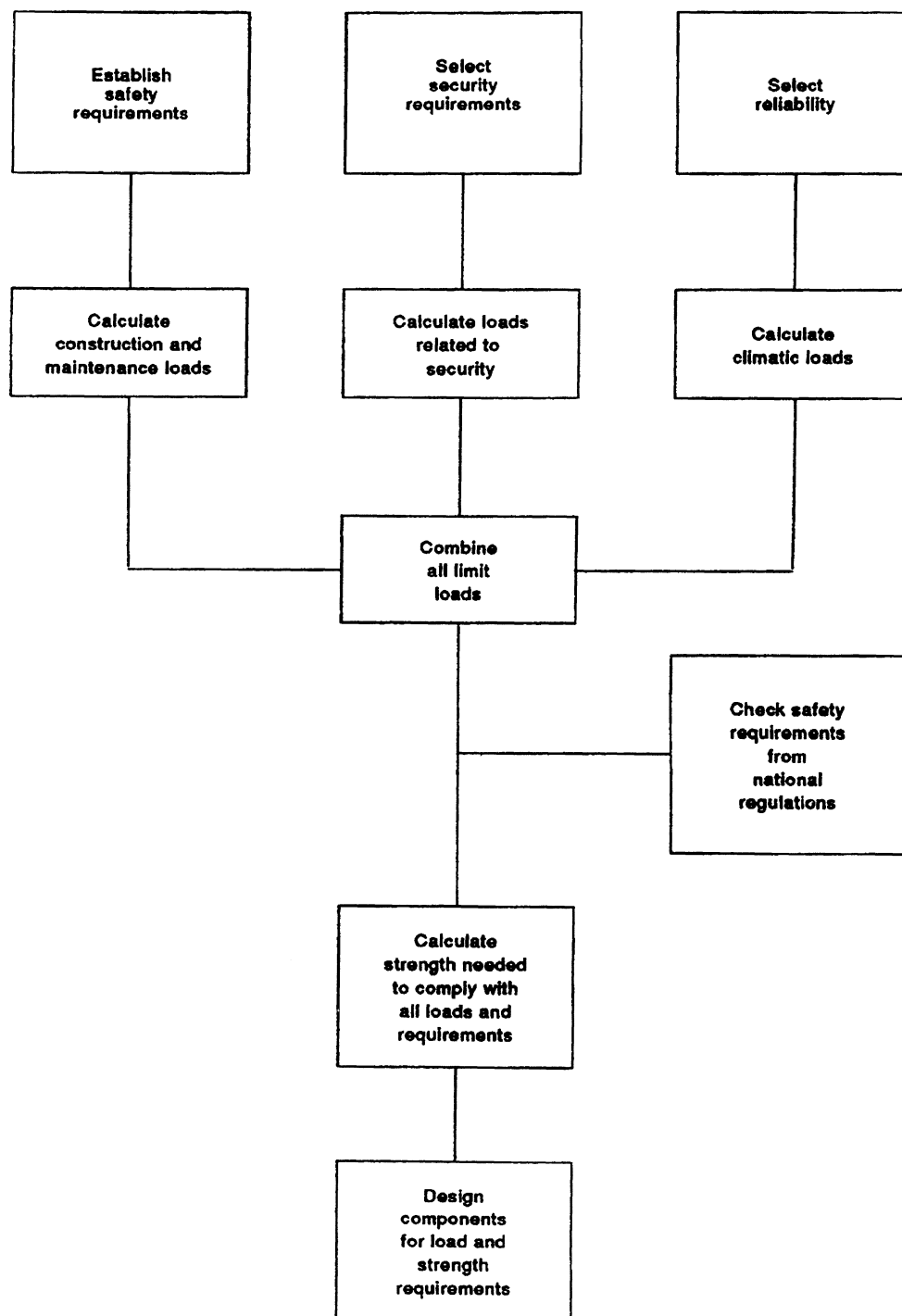


Figure 2 — Methodology for the design of transmission lines

2.1.3.3 Additional requirements

A higher security could be justified for some transmission lines either due to their importance in the network or because they are subjected to severe ice loadings.

In such a case additional measures or loadings which are listed in 3.6.3.3, could be used for increasing security according to the experience and to the type of line to be designed.

2.1.4 Safety requirements

Safety requirements are meant to ensure that construction and maintenance do not pose safety hazards to workers.

The safety requirements of this report are provided in addition to statutory and/or national regulations.

These requirements consist of special loads for which line components (mostly towers) have to be designed. Details concerning construction and maintenance loads are given in section 3 "Loadings".

2.2 Design criteria

2.2.1 General

Limit load concept is used throughout this report. Limit loads, which are referred to as Q_T , are generally derived from climatic data⁷⁾ based on a return period of T years, or, in cases when climatic data are not available, limit loads can be selected, based on experience or by comparison with existing practice. In the latter case, the reliability of a line designed according to this report may not be known; however, overall design consistency is achieved.

In the design process, the following conditions have to be checked:

$$\text{Load effect} < \text{Strength}$$

or,

$$\gamma_u Q_T < \Phi R_c$$

or,

$$\text{Load factor} \times \text{limit loads} < \text{Strength factor} \times \text{characteristic strength}$$

As shown in Table 5, three cases have to be considered.

Table 5 — Design conditions

Condition (or requirement)	Type of loads	Limit state
Reliability	Climatic, ice, wind, ice + wind, with a return period T	Damage limit ^a
Security	Failure containment (torsional and longitudinal)	Failure limit ^b
Safety	Construction and maintenance loads	Damage limit ^a
^a There should not be any permanent deformation under these loads (damage limit of components should not be exceeded). ^b Since the purpose of these loads is to prevent cascading failure in a line that has already failed, it is conceivable and economical to use the highest possible strength as long as failure does not propagate without control.		

⁷⁾ Load Q_T , when derived from extreme data analysis at weather stations should reflect the maximum loading intensity, which might occur within the space covered by the line (adjustment for space or length of the line). Directional tendencies of extreme climatic events, whenever proven, could be incorporated into the load distribution function.

2.2.2 Design equation

$$\gamma_u Q_T = \Phi_R R_c \quad (5)$$

$$\Phi_R = \Phi_S \Phi_N \Phi_Q \Phi_C \quad (6)$$

where:

- γ_u = factor dependent on span dispersion and applied to vertical and transverse loads of towers. This factor should be considered equal to 1,0 except where use factor data are predictable or available. In such a case refer to Annex A for calculation of γ_u
- Q_T = load corresponding to a return period T , or selected by calibration or experience if data are not available. These loads are limit loads used for design purposes
- Φ_R = global strength factor equal to the product of Φ_S , Φ_N , Φ_Q and Φ_C
- Φ_S = factor related to coordination of strength between components from Table 9
- Φ_N = factor related to the number N of components subjected to the critical load. N is the total number of components derived from the information given in Table 6 and Table 7 and Φ_N is given in Table 8
- Φ_Q = factor related to the quality level of the component during fabrication and construction
- Φ_C = factor related to the relationship between the actual exclusion limit of R_c and the assumed value of $e = 10\%$ (this assumption leads to safer designs). For practicality this factor is considered equal to 1,0 or it could be calculated using Annex D
- R_c = the characteristic or nominal strength; it corresponds to the damage limit for all loads related to reliability and safety conditions and to failure limit for all loads related to security

2.2.3 Factor γ_u

Due to standardization and reduced number of tower types, many towers in a transmission line are not used at their maximum design parameters. This fact contributes to an increase in the overall reliability, especially when dealing with loading events where the maximum intensity is not widespread.

Use factors, U , (ratio of actual to maximum spans) were found to have predictable patterns in well optimized transmission lines (see Annex A), which allows modelling of this variable into the general reliability equation.

Some techniques have been developed in order to include the beneficial effect of use factor in the general load-strength relation through the application of a reduction factor γ_u on limit loads. However for some transmission lines where it is difficult to predict span variation while in the design phase of towers, it may be acceptable to neglect the effect of use factors and consider γ_u equal to 1,0. The design will then be on the safe side, but the desired strength coordination between components could be altered.

When the designer has a reliable prediction model of the variation of the use factors of the line, he can use the technique given in Annex A in order to incorporate this effect into line design. If however a line crosses different terrains with the same type of towers, the designer has to use the largest value of γ_u obtained from each section.

2.2.4 Number of components subjected to maximum load intensity related to factor Φ_N

On the load side of the reliability equation, the load density function already includes the notion of space covered by the transmission line. However, when an extreme climatic event occurs within this space, its maximum intensity does not necessarily extend to the whole space.

For example, events such as low temperature, rain and hurricanes may affect with full intensity a large number of components in this space, while other types of climatic events, such as freezing rain or tornadoes, have a maximum intensity which affects a very limited number of components.

The determination of the number of components subjected to the maximum load intensity is important in the design because the risk of “finding” a weak tower increases with this number of components.

Current studies and measurements give little information on the space covered by the maximum intensity of storms. One of the possible ways of obtaining these data is by inference from failures that occurred due to these events (we should distinguish between failures caused directly by the climatic event and secondary failures triggered by the initial failure) as well as by observations made specially during and immediately after storms.

Under a widespread freezing rain storm, the maximum ice accretion rarely covers more than a few kilometres with a possible coverage of up to 20 towers.

On the other hand, the analysis of some past failures that occurred due to extreme winds indicate that these wind intensities rarely apply to more than a few towers.

Available experience suggests that the number of towers subjected to maximum load intensity may vary according to Table 6, assuming a typical span of 400 m. Consequently, any value in the range given in Table 6 could be used for design purposes, as dictated by past experience. Other values should be used if substantiated by data, by special local conditions or by experience.

Table 6 — Range of spatial coverage of maximum load intensity (given in number of towers)

Loading	Flat to rolling terrain	Mountains
Maximum gust wind	1 to 5	1 or 2
Maximum ice	10 to 50	1 to 10
Maximum ice + wind	1 to 5	1 to 5

In the absence of specific experience, the number of towers subjected to the maximum intensity of climatic events can be derived from Table 7.

Table 7 — Number of towers subjected to maximum load intensity

Loading	Flat to rolling terrain	Mountains
Maximum gust wind	1	1
Maximum ice	20	2
Maximum ice + wind	1	1

The number of components other than towers can be directly derived from the number of towers thus selected.

2.2.5 Strength factor Φ_N related to number of components

For the number of components determined according to 2.2.4, the strength coefficient Φ_N can be determined from Table 8 (see section 5 for detailed calculation method).

Table 8 — Strength factor Φ_N related to the number N of components subjected to the critical load intensity

N	Strength dispersion v_R						
	5 %	7,5 %	10 %	15 %	20 %	25 %	30 %
1	1,00	1,00	1,00	1,00	1,00	1,00	1,00
2	0,98	0,98	0,97	0,94	0,91	0,87	0,84
5	0,96	0,94	0,92	0,85	0,80	0,72	0,64
10	0,94	0,92	0,89	0,81	0,72	0,62	0,51
20	0,93	0,90	0,85	0,77	0,66	0,53	0,38
40	0,92	0,87	0,83	0,72	0,59	0,44	0,26
80	0,91	0,86	0,79	0,68	0,53	0,36	0,16
160	0,90	0,84	0,78	0,64	0,48	0,29	0,07

2.2.6 Strength factor Φ_S related to coordination of strength

As discussed earlier, it may be desirable in a transmission line system to design some components to be more reliable than others in order to minimize the consequences of a possible failure due to climatic overloads (i.e. repair time, secondary failure, etc.).

On the basis of the criteria in 1.5 of section 1, it is suggested that foundations of a tower be more reliable than the tower itself, and that conductors and angle towers be more reliable than the tangent tower.

In order to achieve such strength coordination, a strength factor Φ_S is applied to the strength of components required to be more reliable. This factor depends on the dispersion of both components and the values given in Table 9 are based on a confidence of 90 % that the second component R_2 will not fail before the first R_1 . For more detailed values, see Table 28 and 5.4.2.

Table 9 — Values of Φ_S

V_{R2}	V_{R1}	
	5 %	10 %
5 % to 10 %	0,92	0,82
10 %	0,94	0,86

2.2.7 Strength factor Φ_Q related to quality

Whenever the strength of a component is derived from tests performed under ideal conditions on samples specially manufactured for the tests, it is advisable to reduce the characteristic strength by a factor Φ_Q related to quality, since in practice the component will be mass produced and will be used under conditions different from those of the tests. The suggested range of Φ_Q is 0,9 to 1,0; the value of $\Phi_Q = 1,0$ is used only whenever type or routine tests are done under conditions similar to actual construction methods, otherwise Φ_Q shall be equal to 0,90 to 0,95 depending on the judgement and experience of the designer.

2.3 Design criteria for towers

2.3.1 Loads on towers

Loads Q_T applied to towers at attachment points of conductors and ground wires have three components:

- a) vertical component Q_{Tv} ;
- b) wind component Q_{Tw} ;
- c) tension component Q_{Tt} .

Thus, tower loads in general become:

$$\text{Tower loads} = \text{effect of} \begin{vmatrix} Q_{Tv} \\ Q_{Tw} \\ Q_{Tt} \end{vmatrix} + \text{loads on tower body.}$$

2.3.2 Strength of towers

Towers shall be designed for a characteristic strength R_c equal to:

$$R_c = \frac{\text{tower loads}}{\Phi_S \Phi_N \Phi_Q} \quad (7)$$

2.3.3 Tower tests

Towers subjected to type tests shall withstand loads equivalent to R_c . Tests shall meet IEC 652.

2.4 Design criteria for foundations

2.4.1 Foundation loads

The maximum reactions on foundations are obtained from the design of towers subjected to the loads defined in 2.3.1 using conventional methods and appropriate wind-weight span combinations, tower legs, and body extensions.

The reactions thus obtained are considered to be the design loads on foundations.

2.4.2 Strength of foundations

Foundations shall have a characteristic strength R_c calculated from the following equation:

$$R_c = \frac{\text{design loads foundations}}{\Phi_S \Phi_N \Phi_Q} \quad (8)$$

2.5 Design criteria for conductors and earth wires

Conductors and earth wires are designed for the most critical resultant load (vertical with or without transverse) per unit length applied to the corresponding ruling span⁸⁾.

Φ_S is taken equal to 1,0 because the maximum tension being usually lower than the damage limit (see Table 19) leads to the fact that wires are more reliable than towers.

$$\Phi_Q = 1,0$$

2.6 Design criteria for insulators and hardware

Design of insulators and hardware follows the same principles outlined for towers and foundations except for the following differences:

$\Phi_S = 0,90$ for all hardware (dispersion of strength of hardware does not usually exceed 7 %).

Φ_N for suspension hardware can be obtained from Table 8, with N being multiplied by the number of suspension hardware per tower; and for insulators, it can be obtained from the same table with N being multiplied by the number of insulators per tower.

$$\Phi_Q = 1,0$$

Section 3. Loadings

3.1 General

3.1.1 Scope

The object of this section is to define loadings applied to transmission line components.

3.1.2 Classification of loads

Overhead transmission lines are subjected to various loads during their lifetime which are classified into three distinct categories:

- a) climatic loads which are related to the reliability requirements;
- b) failure containment loads which are related to the security requirements;
- c) construction and maintenance loads which are related to safety requirements.

Requirements for each loading category are detailed in this section as follows:

3.2: wind loads

3.3: ice without wind

3.4: ice with wind

3.5: loads for construction and maintenance

3.6: loads for failure containment

3.2 Climatic loads, wind

3.2.1 Object

Clause 3.2 defines the procedures which can be applied for obtaining and interpreting meteorological data required for the design of overhead lines. It also contains a method which can be used to evaluate the response of the line components (conductors, insulators, supports) to the effect of wind and associated temperatures.

⁸⁾ Since span variation is already included in the ruling span calculations, the γ_u is always equal to 1,0 for all loads related to the conductors' tension.

3.2.2 General conditions

Although this subclause applies in principle to any overhead line, it is better limited to the following conditions:

- Span lengths between 200 m and 800 m, as calculations of the various coefficients (in particular for gusty winds) have not been checked for span lengths beyond this range. However, for span lengths greater than 800 m, a gust coefficient corresponding to 800 m span could be chosen with safety.
- Height of supports less than 60 m. Higher supports could be designed following the same principles, but the calculated wind actions would need to be checked.
- Altitude of crossed areas not exceeding 1 300 m above the average level of the topographic environment, except where specific study results are available.
- An adjustment may be made for lines in mountain areas because the roughness can vary according to the vegetation (large trees), snow-covered slopes and rough topography. Such areas shall be defined by national codes of practices.

3.2.3 Definitions

3.2.3.1 Ground roughness

Wind action depends on the ground roughness. The greater this roughness, the more turbulent and slower is the wind. The ground roughness has an influence both on the determination of the wind velocity for the design and on the determination of the gust factor.

Four categories of ground, of increasing roughness, are considered as indicated in Table 10.

Table 10 — Definition of ground roughness^a

Roughness	Characteristics of the ground crossed by a line
A	Large stretch of water up-wind, flat coastal area, flat deserts
B	Open country with very few obstacles, for instance, moorlands or cultivated fields with a few trees or buildings
C	Terrain with numerous small obstacles of low height (hedges, trees and buildings)
D	Suburban areas or terrains with many tall trees

^a Lines crossing highly urbanized areas should be considered in a D ground roughness. The value of the roughness coefficient is very difficult to assess for these areas.
For a line which follows the ridge of a hill, a ground roughness which is one category below the one chosen for the area should be chosen. For a line running along a valley, the C roughness category should be chosen for all cases, whatever the ground characteristics may be.

3.2.3.2 Meteorological wind velocity V

V is the meteorological wind velocity, defined as follows: average velocity of the wind during a 10 min period at a level of 10 m above the ground: in relatively open country (roughness B).

A procedure is described in Annex E to compute V whenever the meteorological velocity is not measured in the above-mentioned conditions.

3.2.3.3 Maximum yearly wind velocity V_m

This velocity V_m is the maximum of V measured over a year.

3.2.4 Loading assumptions

Loading assumptions mainly include:

- high wind assumption;
- reduced wind associated with minimum temperature.

Minimum temperature assumption is never crucial for tangent supports, but must be checked for angle or dead-end supports, particularly for short spans.

3.2.4.1 High wind

3.2.4.1.1 Determination of the high wind velocity V_M

The choice of the high wind velocity V_M depends upon the reliability level for which the line will be designed (see 2.1.2).