f) determine the expected number of lifetime cycles in each bin using the data when the load bin is below the threshold and the fitted load distribution when the load bin is above the threshold. This results in

$$n'_{jk} \approx \left(\frac{Lifetime}{T}\right) P_j \begin{Bmatrix} m_{jk} & \text{if } S_k \text{ is below the j}^{\text{th}} \text{ threshold} \\ M_j \left(F\left(S_k + \frac{\Delta S_k}{2} \middle| V_j, T \right) - F\left(S_k - \frac{\Delta S_k}{2} \middle| V_j, T \right) \right) & \text{if } S_k \text{ is above the j}^{\text{th}} \text{ threshold} \end{Bmatrix} \quad \text{(G.12)}$$

where m_{jk} is the number of simulation fatigue cycles counted in the data for the j^{th} wind speed bin and k^{th} load bin below the threshold, M_j is the number of fatigue cycles counted in the simulation above the threshold, and $P_j = e^{-\pi\left(\frac{V_j - \Delta V_j/2}{2V_{ave}}\right)} - e^{-\pi\left(\frac{V_j + \Delta V_j/2}{2V_{ave}}\right)}$ is the fraction of time the wind speed is in bin j for the assumed Rayleigh wind speed distribution.

1) Sum the damage using the left hand side of equation (G.9).

2) Sum the total lifetime damage from all fatigue load cases.

In using this procedure, care must be taken that

a) the resolution of the wind speed and load range bins is sufficient for the desired numerical precision, and

b) sufficiently large values of load range are used to adequately represent the tail of the long-term load distribution.

The first issue may be addressed by approximating the error as half the difference between results computed by two different bin resolutions skipping data from every other wind speed or load range. An alternative would be to compute the damage summation using the endpoints for the bin values instead of the central values to bound the result.

The second issue may be addressed by progressively increasing the highest load range bin value until a negligible increase in the lifetime damage is observed. Note because the ratio $\frac{Lifetime}{T}$ is a large number, the largest required load bin may be significantly larger than the largest cycle observed in the simulation data. This results because the total simulated load time history is much smaller than the turbine lifetime, and statistical extrapolation is required to accurately estimate damage from the tail of the long-term load distribution.

G.2 Reference documents

Dowling, N.E., *Fatigue Failure Predictions for Complicated Stress-strain Histories*, J. of Materials, v.7, n.1, Mar., 1972, pp. 71-87.

Matsuishi, M. and Endo, T., *Fatigue of Metals Subjected to Varying Stress*, Proc. Japan Soc. of Mech. Engrs., n. 68-2, 1968, pp. 37-40.

Miner, M.A. *Cumulative Damage in Fatigue*, J. of Applied Mech., v.12, 1945, pp. A159-A164.

Moriarty, P. J. and Holley, W. E., *Using Probabilistic Models in Wind Turbine Design*, Proc. ICASP9, San Francisco, CA, July 6-9, 2003.

Palmgren, A. , *Die Lebensdauer von Kugellagern*, Zeitschrift der Vereines Deutscher Ingenieure, v. 68, n. 14, 1924, pp. 339-341.

Annex H
(informative)

Contemporaneous loads

H.1 General

Detailed structural analyses of wind turbine components commonly use a finite element or other suitable model for determination of the local stress or strain resulting from the loading applied to the component. Such analyses often define a suitable interface plane where the applied loads are acting (e.g. the yaw bearing interface, defining the tower top loading). In this case, there are six load components defining the boundary conditions for loading, three forces, F_x, F_y, and F_z, and three moments, M_x, M_y, and M_z. For convenience here, the x, y axes are taken to be in the loading plane and the z axis normal to the plane. To describe the extreme loading situations, a load matrix is often defined as shown in Table H.1.

Table H.1 – Extreme loading matrix

	F_x	F_y	F_z	M_x	M_y	M_z	F_R	θ_F	M_R	θ_M
Max.										
Min.										
Max.										
Min.										
Max.										
Min.										
Max.										
Min.										
Max.										
Min.										
Max.										
Min.										
Max.										
Max.										

In this table, each column represents a load component value delineated by the heading at the top. Each row represents contemporaneous values (i.e. all values occurring at the same time) and the shaded cell shows the specific component that has either a maximum or minimum value as indicated on the left. These maximum and minimum values are intended to cover the full range of values for that particular load component. The detailed structural model is then exercised using each of the rows to determine resulting local stress or strain values, which are compared to an appropriate failure criterion. When the structural stiffness and strength in response to loading in the plane is similar for the different loading directions, the most extreme loading can result when both x and y components are large in magnitude but not at their very largest values. Thus, the in-plane vector resultant values are also displayed in the additional columns on the right and the rows at the bottom. These in-plane resultants are defined as

$$F_R = \sqrt{F_x^2 + F_y^2} \text{ and } M_R = \sqrt{M_x^2 + M_y^2} \tag{H.1}$$

The angular directions of these resultants are also defined as

$$\theta_F = \arctan(F_x / F_y) \text{ and } \theta_M = \arctan(M_x / M_y) \tag{H.2}$$

The values in the table are determined by post-processing analysis of the time series for the six load components determined as the outputs from the complete wind turbine dynamic simulation code. In this analysis, the time series are searched for the maximum and minimum values for each component as well as the maxima for the resultants. The contemporaneous values associated with each of these corresponding time points are then inserted in the rows of the table. Each of the load cases defined in Clause 7 are analyzed in this way and the most extreme loading in each row from the different load cases is then used to define an overall loads envelope for that part of the wind turbine.

In the following, two approaches are given. Note that caution should be exercised in order to obtain conservative contemporaneous loads.

H.2 Scaling

The approach comprises the following steps.

- For each cross section and load component one bin of the considered load case delivers the maximum characteristic load.
- A time series from this bin being close with its maximum within ± 5 % to this characteristic load is selected.
- The maximum of this time series is scaled to the characteristic load. The obtained scaling factor is then also applied to all contemporaneous load components to this selected maximum of this time series.
- For each load component one load case series is obtained to be used for extreme design load analysis.
- For minimum values the procedure is applied accordingly.

H.3 Averaging

The approach comprises the following steps.

- For a load case consisting of more than one realisation the ultimate positive load is calculated as the mean of the maximum of each realisation.
- Contemporaneous loads are calculated as the mean of the absolute contemporaneous values of each realisation. Signs on the contemporaneous loads are applied in accordance with the signs of the contemporaneous loads of the realisation with the highest load.
- The ultimate negative load is calculated as the mean of the minimum of each realisation. Contemporaneous loads are calculated in the same manner as in the positive case.
- The ultimate absolute load is taken as the maximum of the absolute values of the means of the maximum and means of the minimum loads described above with corresponding contemporaneous values.

Bibliography

The following standards are relevant to the design of wind turbines:

IEC 60034 (all parts), *Rotating electrical machines*

IEC 60038, *IEC standard voltages*

IEC 60146 (all parts), *Semiconductor converters*

IEC 60173:1964, *Colours of the cores of flexible cables and cords*

IEC 60227 (all parts), *Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 V*

IEC 60245 (all parts), *Rubber insulated cables ~~of~~ – Rated voltages up to and including 450/750 V*

IEC 60269 (all parts), *Low-voltage fuses*

IEC 60287 (all parts), *Electric cables – Calculation of the ~~continuous~~ current rating ~~(100 % load factor)~~*

IEC 60439 (all parts), *Low voltage switchgear and control gear assemblies*

IEC 60446:~~1999~~ 2007, *Basic and safety principles for man-machine interface, marking and identification – Identification of conductors by colours or ~~numerals~~ alphanumerics*

IEC 60529:1989, *Degrees of protection provided by enclosures (IP Code)*

IEC 60617, *Graphical symbols for diagrams*

IEC/TR 60755:~~1983~~ 2008, *General requirements for residual current~~-~~operated protective devices*

IEC 60898~~:1995~~, *Electrical accessories – Circuit breakers for overcurrent protection for household and similar installations*

IEC 61310-1:~~1995~~ 2007, *Safety of machinery – Indication, marking and actuation – Part 1: Requirements for visual, auditory and tactile signals*

IEC 61310-2:~~1995~~ 2007, *Safety of machinery – Indication, marking and actuation – Part 2: Requirements for marking*

ISO 3010:2001, *Basis for design of structures – Seismic actions on structures*

ISO 8930:~~1993~~ 1987, *General principles on reliability for structures – List of equivalent terms*

ISO 9001, *Quality management systems – Requirements*

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Part 1: Design requirements

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CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND TURBINES –

Part 1: Design requirements

FOREWORD

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This Consolidated version of IEC 61400-1 bears the edition number 3.1. It consists of the third edition (2005-08) [documents 88/228/FDIS and 88/232/RVD] and its amendment 1 (2010-10) [documents 88/374/FDIS and 88/378/RVD]. The technical content is identical to the base edition and its amendment.

This Final version does not show where the technical content is modified by amendment 1. A separate Redline version with all changes highlighted is available in this publication.

This publication has been prepared for user convenience.

International Standard IEC 61400-1 has been prepared by IEC technical committee 88: Wind turbines.

The main changes with respect to the previous edition are listed below:

– the title has been changed to “Design requirements” in order to reflect that the standard presents safety requirements rather than requirements for safety or protection of personnel;
– wind turbine class designations have been adjusted and now refer to reference wind speed and expected value of turbulence intensities only;
– turbulence models have been expanded and include an extreme turbulence model;
– gust models have been adjusted and simplified;
– design load cases have been rearranged and amended;
– the inclusion of turbulence simulations in the load calculations is emphasised and a scheme for extreme load extrapolation has been specified;
– the partial safety factors for loads have been adjusted and simplified;
– the partial safety factors for materials have been amended and specified in terms of material types and component classes;
– the requirements for the control and protection system have been amended and clarified in terms of functional characteristics;
– a new clause on assessment of structural and electrical compatibility has been introduced with detailed requirements for assessment, including information on complex terrain, earthquakes and wind farm wake effects.

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

A list of all parts of IEC 61400 series, under the general title *Wind turbine generator systems*, can be found on the IEC website.

The committee has decided that the contents of the base publication and its amendment will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

• reconfirmed;
• withdrawn;
• replaced by a revised edition, or
• amended.

INTRODUCTION

This part of IEC 61400 outlines minimum design requirements for wind turbines and is not intended for use as a complete design specification or instruction manual.

Any of the requirements of this standard may be altered if it can be suitably demonstrated that the safety of the system is not compromised. This provision, however, does not apply to the classification and the associated definitions of external conditions in Clause 6. Compliance with this standard does not relieve any person, organization, or corporation from the responsibility of observing other applicable regulations.

The standard is not intended to give requirements for wind turbines installed offshore, in particular for the support structure. A future document dealing with offshore installations is under consideration.