TECHNICAL SPECIFICATION

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Wind turbine generator systems –

Part 13:
Measurement of mechanical loads

Aérogénérateurs –

Partie 13: Mesure des charges mécaniques

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

WIND TURBINE GENERATOR SYSTEMS –

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FOREWORD

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 61400-13, which is a technical specification, has been prepared by IEC technical committee 88: Wind turbine systems.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
88/120/CDV	88/132/RVC

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 3.

The committee has decided that the contents of this publication will remain unchanged until 2004. At this date, the publication will be

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- withdrawn;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

A bilingual version of this technical specification may be issued at a later date.

INTRODUCTION

In the process of structural design of a wind turbine, thorough understanding about, and accurate quantification of, the loading is of utmost importance.

In the design stage, loads can be predicted with aeroelastic models and codes. However, such models have their shortcomings and uncertainties, and they always need to be validated by measurement. Furthermore, measurements can be used for the direct determination of structural loads in specific conditions.

Mechanical load measurements can be used both as the basis for design and as the basis for certification. Design aspects for wind turbines are covered by IEC 61400-1 whilst certification procedures are described in IEC WT 01*. This technical specification is aimed at the test engineer who will design and implement the test programme to meet the specific design or certification needs. The specification provides specific guidance on load measurements on key structural components and load paths. Data analysis procedures are also outlined. The specification describes how to collect various types of time-series or statistical load information. Two types of situation are considered – steady-state operation and transient operation. The prescribed measurement load cases mirror the design load cases within IEC 61400-1, the wind turbine safety standard.

* IEC WT 01:2001, IEC System for Conformity Testing and Certification of Wind Turbines – Rules and procedures

WIND TURBINE GENERATOR SYSTEMS –

Part 13: Measurement of mechanical loads

1 General

1.1 Scope and object

This part of IEC 61400 deals with mechanical load measurements on wind turbines. It mainly focuses on large (>40 m^2) electricity generating horizontal axis wind turbines. However, the methods described might be applicable to other wind turbines as well (for example, mechanical water pumpers, vertical axis turbines).

The object of this specification is to describe the methodology and corresponding techniques for the experimental determination of the mechanical loading on wind turbines. This technical specification is intended to act as a guide for carrying out measurements used for verification of codes and/or for direct determination of the structural loading. This specification is not only intended as one coherent measurement specification but can also be used for more limited measurement campaigns.

1.2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 61400. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of IEC 61400 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60050(415):1999, *International Electrotechnical Vocabulary (IEV) – Part 415: Wind turbine generator systems*

IEC 61400-1:1999, *Wind turbine generator systems – Part 1: Safety requirements*

IEC 61400-12:1998, *Wind turbine generator systems – Part 12: Wind turbine power performance testing*

ISO 1995, *Guide to the expression of uncertainty in measurement*

ISO 2394:1998, *General principles on reliability for structures*

1.3 Definitions

For the purpose of this technical specification, the definitions related to wind turbine systems or wind energy in general of IEC 60050(415) and the following definitions apply.

1.3.1
blade
rotating aerodynamically active part of the rotor

1.3.2
blade root
that part of the rotor blade that is connected to the hub of the rotor

1.3.3
calibration load
forces and moments applied during calibration

1.3.4
capture matrix
organization of the measured time series according to mean wind speeds and turbulence intensities

1.3.5
chord
length of a reference straight line (the chord line) that joins, by certain defined conventions, the leading and trailing edges of a blade airfoil cross-section

1.3.6
chord line
reference straight line that joins, by certain defined conventions, the leading and trailing edges of a blade airfoil cross-section

1.3.7
design loads
loads that the turbine is designed to withstand. They are obtained by applying the appropriate partial load factors to the characteristic values

1.3.8
flap
direction which is perpendicular to the swept surface of the undeformed rotor blade axis

1.3.9
hub
fixture for attaching the blades or blade assembly to the rotor shaft

1.3.10
lead-lag
direction which is parallel to the plane of the swept surface and perpendicular to the longitudinal axis of the undeformed rotor blade

1.3.11
nacelle
housing which contains the drive train and other equipment on the top of a HAWT tower

1.3.12
natural frequency (eigenfrequency)
frequency at which a structure will choose to vibrate when perturbed and allowed to vibrate freely

1.3.13
outboard
towards the blade tip

1.3.14
partial safety factors
factors that are applied to loads and material strengths to account for uncertainties in the representative (characteristic) values

1.3.15
radial position
distance from the rotor centre in a plane perpendicular to the rotor axis

1.3.16
rotor centre
point on the main shaft in the plane perpendicular to the main shaft that contains the blade co-ordinate origin of the reference blade

1.3.17
rotor plane
plane perpendicular to the main shaft and which includes the rotor centre

1.3.18
spanwise
direction parallel to the longitudinal axis of a rotor blade

1.3.19
steady-state operation
state of operation of the turbine during which it remains in a steady state such as during power production, power production + fault condition and when parked or idling and for which the external conditions also remain essentially steady or characterized by stationary random processes for the duration of the measurement

1.3.20
transient event
event during which the state of operation of the wind turbine changes, such as during shut-down

1.3.21
test load
forces and moments applied during a test

1.3.22
turbulence intensity
turbulence intensity is the ratio of the standard deviation of the wind speed in a given time interval to the mean wind speed in the same time interval

1.3.23
yaw position
angle between the vertical projection of the centre line of the main shaft on the tower base and the X-axis of the tower co-ordinate system (which is to be defined as appropriate according to the site and the shape of the tower cross-section). The yaw position is positive rotating counter-clockwise (top view)

1.4 Symbols, units and abbreviations

1.4.1 Symbols and units

ε	strain	–
φ_F	angle for yaw misalignment	[°]
B	number of blades	–
f	frequency	[Hz]
F	forces	[N]
I	turbulence intensity	–
I	index for wind speed bin	–
j	index for accumulated number of alternating load cycles	–
k	index for specific load	–
M_{be}	blade-root lead-lag bending moment	[Nm]
M_{bf}	blade-root flap-bending moment	[Nm]
M_{eq}	equivalent load	[Nm, N]

M_{tm}	tower base normal bending moment	[Nm]
M_{tl}	tower base lateral bending moment	[Nm]
M_{tilt}	rotor tilt moment	[Nm]
M_{ttm}	tower top normal moment	[Nm]
M_{ttl}	tower top lateral moment	[Nm]
M_{ttt}	tower top torsion moment	[Nm]
m	slope of S-N curve	–
n	number of measurements/results	–
N	number of cycles to failure	–
R	rotor radius	[m]
R^{e}_{ijk}	extrapolated load range	[Nm, N]
R^{m}_{ijk}	measured load range	[Nm, N]
S	load amplitude	[Nm, N]
s_{I}	type A standard uncertainty	–
T_{rotor}	rotor torque	[Nm]
u	measured value for uncertainty assessment	–
u_{I}	type B standard uncertainty	–
x_{b}, y_{b}, z_{b}	blade co-ordinates (see figure A.1)	–
x_{h}, y_{h}, z_{h}	hub co-ordinates (see figure A.2)	–
x_{I}	input quantity	–
x_{n}, y_{n}, z_{n}	nacelle co-ordinates (see figure A.3)	–
x_{t}, y_{t}, z_{t}	tower co-ordinates (see figure A.4)	–
y	quantity to be measured	–
v_{e1}	extreme wind speed with return period of one year	[m/s]
v_{hub}	wind speed at hub height	[m/s]
v_{in}	cut-in wind speed	[m/s]
v_{r}	rated wind speed	[m/s]
v_{out}	cut-out wind speed	[m/s]

1.4.2 Abbreviations

MLC	measurement load case
DLC	design load case
SO	steady-state operation
TE	transient event
TI	turbulence intensity

2 Safety during testing

Certain measurement load cases involve deliberate operation of the turbine in extreme and/or emergency fault conditions (for example, grid loss). As the purpose of the tests and measurements in most cases is to verify loads on a prototype turbine, it shall not be assumed that the turbine will behave and respond as intended. Therefore, such tests shall always be assumed to be dangerous and due regard shall be taken for personnel safety. On this basis, such tests shall be initiated and observed from a safe position, usually at a certain distance upwind the rotor plane and they shall not be carried out with personnel inside or on the nacelle or tower or within the rotor plane. All tests and test procedures shall be agreed with the turbine manufacturer before implementation to ensure that the turbine integrity, and hence that personnel safety, is not compromised. Requirements from existing applicable safety standards shall be followed.

3 Load measurement programmes

3.1 General

The measurement programme involves collecting both a comprehensive statistical database and a set of time series, which define the behaviour of the turbine in certain specific situations. In this clause, a system of measurement load cases (MLCs) is defined to determine the wind turbine loads in conditions corresponding to a selection of design load cases (DLCs) of IEC 61400-1. The MLCs may directly be used for documentation of the load in relation to the DLCs, or the MLCs may provide a basis for the validation of calculation models at specific and well-defined external conditions. Subsequently, the models can be used to estimate the loads at the design conditions. This clause also provides specifications for the quantities to be measured.

3.2 Measurement load cases (MLCs)

3.2.1 General

This subclause describes how to build up load measurement campaigns from a number of well-defined MLCs. The MLCs are defined in relation to the DLCs, described in IEC 61400-1. Hence, not all DLCs can be reasonably verified by measurement.

The MLCs define the main external conditions and the operational conditions of the turbine during the measurement campaigns. The external conditions include meteorological parameters such as wind speed, turbulence intensity and air density. The operational conditions include operational parameters such as rotational speed, yaw error, electrical power and blade pitch angle. The operational conditions depend on the wind turbine configuration and shall be specified for each particular case.

Due to the stochastic character of the external conditions, measurements of each MLC have to be repeated several times in order to reduce the statistical uncertainty. The minimum number of measurements at each MLC is specified in this subclause.

Some of the DLCs of IEC 61400-1 and covered by MLCs defined in this specification are specified at external conditions that are difficult to achieve during a measurement campaign. In particular, the high wind speeds for those DLCs are difficult to obtain during the measurement campaign or at a specific site. For example, it is not possible to forcefully apply the extreme coherent gust to the turbine. In such cases, these load cases shall be assessed at wind speeds which are as high as possible.

The measured time histories are classified in two ways: one considering steady-state operation (SO) and one considering transient events (TE). In this way, all measurements can be classified in measurement load cases which relate to the IEC 61400-1 DLCs.

Tables 1 and 2 show the MLCs that are recommended to be recorded. The MLCs defined in the tables may not be complete. Additional MLCs may be necessary depending on the wind turbine concept and control and safety strategy.

3.2.2 MLCs during steady-state operation

Power production

During power production, measurements shall be performed in the wind speed range from cut-in to cut-out and in a range of turbulence intensity levels described in the following subclause.

Power production with occurrence of fault

According to IEC 61400-1 any fault in the control or protection systems, or any internal fault in the electrical systems being significant for the wind turbine loading, shall be considered to occur during power production. The occurrence of a fault in the control system, which is considered as a normal event, shall be analysed. A typical fault condition could be the operation at extreme yaw misalignment due to a faulty wind vane, which might not be relevant for a free yaw wind turbine. Faults in the protection system or in the internal electrical system, not causing an immediate shut-down of the wind turbine and consequently leading to higher fatigue loading, shall be considered. An example could be operation with one tip brake activated. The possible fault conditions shall be considered for each wind turbine and application in order to define the measurement campaigns.

Parked, idling

The loads on the parked wind turbine, which may be either in a standstill or idling condition, shall be measured. It is recommended that measurements be performed at wind speeds as high as possible.

Table 1 – MLCs during steady-state operation related to the DLCs defined in IEC 61400-1

MLC number	Measurement load case MLC	DLC number (IEC 61400-1)	Wind condition at DLC	Remarks
1.1	Power production	1.2	$v_{in} < v_{hub} < v_{out}$*	In this mode of operation, the wind turbine is running and connected to the grid
1.2	Power production plus occurrence of fault	2.3	$v_{in} < v_{hub} < v_{out}$*	Any fault in the control or protection system, which does not cause an immediate shut-down of the turbine
1.3	Parked, idling	6.2	$v_{in} < v_{hub} < 0{,}75\ v_{e1}$*	When the wind turbine is parked, the rotor may either be stopped or idling

* Has to be divided further into wind speed bins and turbulence bins.

3.2.3 MLCs during transient events

Start-up

This design situation includes all events resulting in loads on the wind turbine during the transients from standstill or idling to power production. The normal start-up of the turbine shall be performed slightly below cut-out wind speed and at cut-in wind speed. If the turbine operates at more than one fixed speed, cut-in on the different rotational speeds shall be evaluated too.

Normal shut-down

This design situation includes all events resulting in loads on a wind turbine during the normal transient caused by going from a power production situation to a standstill or idling condition. The normal shut-down is recommended to be performed at cut-in wind speed, at rated power and at cut-out wind speed.

Emergency shut-down

The loads arising from emergency shut-down shall be considered. It is recommended to perform the emergency shut-down near cut-in wind speed and above rated wind speed.