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Wind energy generation systems -
Part 4-1: Reliability assessment of drivetrain components in wind turbines

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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Wind energy generation systems - Part 4-1: Reliability assessment of drivetrain components in wind turbines

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IEC TS 61400-4-1 has been prepared by IEC technical committee 88: Wind energy generation systems, in co-operation with ISO technical committee 60: Gears. It is a Technical Specification.

It is published as a dual logo technical specification.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
88/1124/DTS	88/1147/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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

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

– reconfirmed,

– withdrawn, or

– revised.

This corrected version of IEC TS 61400-4-1:2026 incorporates the following correction:

– addition in the foreword that this is a double logo technical specification prepared in cooperation with ISO/TC 60

INTRODUCTION

Gearboxes historically have been and still are a large contributor to wind turbine operating expenses and downtime. IEC 61400-4 describes requirements for the specification, design, and verification of gearboxes in wind turbines. This Technical Specification (TS) accompanies IEC 61400-4 and describes a method for the calculation of the design reliability of gearboxes for wind turbines.

The method enables comparison of the calculated reliability of gearbox designs as a function of time. It allows gearbox suppliers, wind turbine manufacturers, wind plant owners, and others to compare different gearbox designs on equal terms. For example, the design reliability can be compared between different gearbox designs for the same load conditions or for the same gearbox in different load conditions. Wind turbine manufacturers and operators can also use the information for defining field service and repair strategies.

Currently, that occur in the field have a standardized or generally accepted calculation method (Hovgaard 2015). Therefore, as illustrated in Figure 1, there is a difference between the calculated failure probability and apparent failure probability observed in the field.

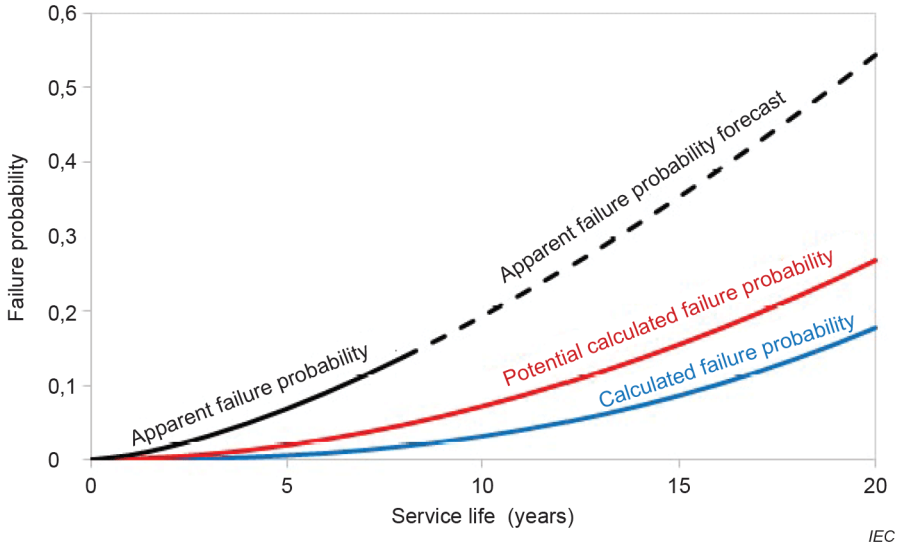


Figure 1 – Calculated design versus apparent failure probability

The method described in this document can accommodate additional failure modes in the future, as long these modes are calculable according to a standardized method and are time related. Figure 1 also indicates how the inclusion of additional failure modes might reduce the gap between calculated and apparent failure probability in the future. Further information can be found in Strasser et al. (2015).

1 Scope

This part of IEC 61400 specifies a method to calculate the design reliability of wind turbines gearboxes covered by IEC 61400-4, based upon failure modes where standardized calculation methods are publicly available.

Currently, not all failure mechanisms that occur in the field have accepted theoretical models. Therefore, the method only provides a quantitative assessment method of the failure mechanisms that can be described with accepted mathematical models for the complete gearbox, stages (functional units), field replaceable units, and individual components.

For the calculable failure mechanisms, it is possible to compare the reliability between different gearbox designs within the limitations of the theoretical models. The use of field-based statistical parameters can improve the accuracy of the calculated reliability.

The calculated design reliability can provide information for the lifecycle management strategy. However, this document does not provide trade-off decisions between higher design reliability and maintenance strategies (e.g. preventive or predictive maintenance). This document does not consider repairable system analysis.

Due to the lack of accepted theoretical models for some failure modes, the model can currently not predict the apparent failure probability in the field.

Neither this document nor IEC 61400-4 specify a minimum value of design reliability.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61400-4, *Wind energy generation systems - Part 4: Design requirements for wind turbine gearboxes*

IEC 61400-8, *Wind energy generation systems - Part 8: Design of wind turbine structural components*

ISO 6336-2:2019, *Calculation of load capacity of spur and helical gears - Part 2: Calculation of surface durability (pitting)*

ISO 6336-3:2019, *Calculation of load capacity of spur and helical gears - Part 3: Calculation of tooth bending strength*

ISO 6336-5:2016, *Calculation of load capacity of spur and helical gears - Part 5: Strength and quality of materials*

ISO 6336-6, *Calculation of load capacity of spur and helical gears - Part 6: Calculation of service life under variable load*

ISO 16281, *Rolling bearings - Methods for calculating the modified reference rating life for universally loaded bearings*

DIN 743 (all parts), *Shafts and axles, calculations of load capacity*

3 Terms, definitions, abbreviated terms, units and conventions

3.1 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

– IEC Electropedia: available at http://www.electropedia.org/

– ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1
apparent failure probability
failure probability observed in the field, including all failure modes, whether they are considered in the calculated system reliability as described in this document or not

3.1.2
component
part in the gearbox system comprising one or more functional elements

EXAMPLE Gear wheel.

3.1.3
failure mode
manner in which a failure occurs

EXAMPLE Gear tooth root bending fatigue fracture.

3.1.4
failure probability
$F(t)$
unreliability function
probability that the time to failure is lower or equal to the time, t

3.1.5
failure probability density function
derivative of the distribution function, which describes the amount of failures as a function of time

3.1.6
field replaceable unit
individual component or gearbox subassembly that can be replaced with relatively low cost and effort, considerably less so than a complete gearbox replacement

EXAMPLE In typical wind turbine gearboxes, the high-speed shaft and bearings are considered as field replaceable units.

3.1.7
functional element
element of a component providing a specific function

EXAMPLE Gear tooth.

Note 1 to entry: A component can have several functional elements.

3.1.8
reliability
probability that a product does not fail during a defined period of time under given functional and environmental conditions

Note 1 to entry: The term probability takes into consideration that various failure events can be caused by coincidental, stochastically distributed causes and that the probability can only be described quantitively. See Bertsche (2008).

3.1.9
reliability function
$\boldsymbol{R(t)}$
survival probability
probability of survival until time, t

3.1.10
system element
unique combination of a failure mode with a functional element of a component

EXAMPLE Gear tooth root bending fatigue fracture of the sun pinion.

3.1.11
system element reliability function
$\boldsymbol{R_{SE}(t)}$
failure behaviour of a system element

3.1.12
system reliability function
$\boldsymbol{R_{S}(t)}$
failure behaviour of the complete system, calculated from the system element failure behaviours and Boolean system theory

3.2 Abbreviated terms and units

This document uses equations and relationships from several engineering specialties. As a result, there are, in some cases, conflicting definitions for the same symbol. All the symbols used in the document are nevertheless listed, but, if there is ambiguity, the specific definition is presented in the clause where they are used in equations, graphs, or text.

$F(t)$	failure probability	%
f_{F1}	conversion factor for tooth root bending strength for failure probability, F	–
f_{H1}	conversion factor for pitting strength for failure probability, F	–
f_{tB}	failure free time factor	–
i	load bin index	–
j	system element index	–
L_F	lifetime where failure of F % of the elements is expected	h
L_{10}	bearing rating life for 10 % failure probability (i.e. 90 % reliability)	h
L_{10mr}	bearing combined modified reference rating life for 10 % failure probability (i.e. 90 % reliability)	h
N_D	number of shaft load cycles for endurance strength according to DIN 743 series	–
$N_{L\ ref}$	number of gear load cycles for endurance limit according to ISO 6336-6	–