# Overview of IEC 61400-9 Standard Probabilistic Design Measures for Wind Turbines

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# PT 61400-9

- Convenor John Dalsgaard Sørenson, Aalborg University, Denmark
- NP Approved by NCs Spring of 2020
- Initial Meeting February, 2021
- Next Meeting April, 2021
- 32 Members from 7 Countries
  - 12 DK, 11 DE, 4 US, 2 UK, 1 ea. CN, ES, NL
  - U.S. Members: L. Manuel, J. Manwell, P. Pourazarm, K. Wetzel

# Background

ISO 2394:2015: General principles for reliability of structures

1. **Semi-probabilistic** method – partial safety factor method
    - Basic calculations of structural resistance and loads employ some probabilistic methods
    - Relationship to “real world” assessed by application of safety factors
2. **Reliability-based** decision making – **probabilistic design**
    - → partial safety factors for design by e.g. IEC 61400-1
3. **Risk-informed** decision making
    - → acceptable and target reliability level for probabilistic design
    - Basis for O&M planning

# Objective

**Minimize the Total Expected Life-Cycle Costs**

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**Minimize Levelized Cost Of Energy (LCOE)**

| | |
|---|---|
| Initial Costs<br>CAPEX | • Dependent on *Reliability* Level |
| Operation & Maintenance Costs<br>OPEX | • Dependent on O&M Strategy, Availability and *Reliability* |
| Failure Costs | • Dependent on *Reliability* |

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# Introduction

Data: observed failure rates

Reliability assessment: Classical reliability theory

Mechanical / electrical components

Data: loads, strengths, …

Probabilistic models for failure events

Reliability assessment: Structural Reliability Theory

- Incl. effect of failure / faults of mechanical / electrical components

Structural components

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# Probabilistic Design of Wind Turbines

**Overall design approach:**

- Combination of
  - Theoretical computational models
  - Test of components / materials
  - Measurements of climatic conditions
  - Full-scale tests / measurements

→ Data-driven

- Information are subject to physical, model, statistical and measurement uncertainties

- Uncertainties can be assessed and combined by use of Bayesian statistical methods

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# Probabilistic Design of Wind Turbines

**Stochastic modeling of loads and load effects:**

- Wind
  - Typhoons
  - Wakes
- Waves
- Currents
- Earthquakes

- Aerodynamics
- Structural dynamics
- Control system

**Stochastic modeling of resistances / material parameters:**

- Blades: composite materials
- Hub: cast steel
- Tower: structural steel / concrete
- Foundation: soil / steel / concrete

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# Probabilistic Design - Reliability level

**IEC 61400-1 ed. 4 (2019):**

Assumptions

- A systematic reconstruction policy is used (a new wind turbine is erected in case of failure or expiry of lifetime).
- Consequences of a failure are ‘only’ economic (no fatalities and no pollution).
- Wind turbines are designed to a certain wind turbine class, i.e. not all wind turbines are ‘designed to the limit’.

→ Target reliability level corresponding to an annual nominal probability of failure:

**$5\ 10^{-4}$** (annual reliability index equal to 3.3)

Application of this target value assumes that the risk of human lives is negligible in case of failure of a structural element.

Corresponds to minor / moderate consequences of failure and moderate / high cost of safety measure (JCSS)

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# Probabilistic Design - Reliability level

## DNVGL-ST-0126: 2018 - Support structures for wind turbines

**2.3.1.5** The target safety level of the normal safety class in this standard is a nominal annual probability of failure of $10^{-4}$.

**Guidance note:**

- The target safety level is the safety level aimed at for the entire structure and will in practice also be the safety level for individual failure modes, since one failure mode is usually dominating. It is intended for use both in case of local failures in hot spots and in case of failures with system effects, such as failure in the weakest link of a series system.
- Designs are accepted with achieved failure probabilities to either side of the nominal target failure probability of $10^{-4}$. The nominal maximum annual acceptable failure probability is $5 \cdot 10^{-4}$. This maximum acceptable failure probability corresponds to what IEC 61400-1 specifies as its target failure probability, but which in background documentation for IEC 61400-1 appears to be a maximum acceptable failure probability.

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# Proposed Content

1. Scope
2. Normative references
3. Terms and definitions
4. Symbols and abbreviated terms
5. Principal elements
    a. General
    b. Target reliability level
    c. Consequence classes
    d. Limit states
    e. Component reliability
    f. Data validity

# Proposed Content

6. Uncertainty representation and modelling
    a. General
    b. External condition uncertainty modelling, incl. model uncertainties
        i. General
        ii. Atmospheric conditions
            1. Normal wind conditions
            2. Extreme wind conditions (non-tropical conditions)
            3. Other, incl. tropical conditions
        iii. Marine conditions
        iv. Soil conditions
    c. Load uncertainty modelling, incl. model uncertainties
        i. General
        ii. Extreme loads
        iii. Fatigue loads
    d. Structural resistance uncertainty modelling, incl. model uncertainties
        i. General
        ii. Geometrical properties
        iii. Material properties
        iv. Resistance models
        v. Fatigue strength and damage accumulation
    e. Component reliability uncertainty modeling
        i. Failure rates
    f. Consequence modelling

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# Proposed Content

7. Performance modelling
    a. General
    b. Structural performance
        i. Design situations, based on DLCs in IEC 61400-1
        ii. Limit states
    c. Component performance
        i. Reliability of electrical components and control & performance system
            1. Failure rates
        ii. Structural and mechanical components
            1. Structural reliability (based on limit states and uncertainty modelling) incl. design situations with fault of electrical components or control & performance system
    d. System performance
        i. Reliability of wind turbine sub-systems, wind turbine and wind farm

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# Proposed Content

8. Assessment of reliability
    a. Reliability-based method
        i. Probability of failure for extreme design situations
        ii. Probability of failure for fatigue design situations
    b. Semi-probabilistic method
        i. Representative and characteristic values
        ii. Partial factor method for extreme and fatigue design situations
        iii. Reliability-based calibration of partial safety factors
9. Site suitability analysis
    a. General
    b. Assessment of site data, incl. uncertainty modelling
    c. Reliability assessment

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