UL 4143

STANDARD FOR SAFETY

Wind Turbine Generator – Life Time Extension (LTE)

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UL Standard for Safety for Wind Turbine Generator – Life Time Extension (LTE), UL 4143

First Edition, Dated February 9, 2018

Summary of Topics

This First Edition of ANSI/UL 4143, the Standard for Wind Turbine Generator – Life Time Extension (LTE), covers requirements for the rules and procedures for the life time extension of wind turbines (LTE).

The new requirements are substantially in accordance with Proposal(s) on this subject dated June 2, 2017 and December 15, 2017.

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Standard for Wind Turbine Generator – Life Time Extension (LTE)

First Edition

February 9, 2018

This ANSI/UL Standard for Safety consists of the First Edition.

The most recent designation of ANSI/UL 4143 as an American National Standard (ANSI) occurred on February 9, 2018. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, and Title Page.

Comments or proposals for revisions on any part of the Standard may be submitted to UL at any time. Proposals should be submitted via a Proposal Request in UL's On-Line Collaborative Standards Development System (CSDS) at https://csds.ul.com.

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INTRODUCTION

1 Scope

1.1 These requirements cover the rules and procedures for the life time extension of wind turbines (LTE).

1.2 These requirements cover the process to obtain risk by relating the severity to their confidence level on accuracy for the failure mode.

1.3 Commercial aspects of wind farm operation are not covered by this Outline of Investigation.

1.4 These requirements are applicable to the on-shore wind turbines.

2 Glossary

2.1 For the purpose of this document, the following terms and definitions apply. Further definitions can also be found in IEC 61400 series.

2.2 CELL – Grouping of wind turbines. A cell defines a group of wind turbines within a wind farm.

2.3 DEL– Damage equivalent load

2.4 DLC – Design load case

2.5 FL – Fatigue load on component

2.6 LDD – Load duration distribution

2.7 LTE – Life time extension, a technical assessment that supports the continued use of a wind asset beyond a previously determined time-based limitation.

2.8 MCP – Measure-correlate-predict

2.9 MLC – Measurement load case

2.10 OEM – Original equipment manufacturer

2.11 RPN – Risk priority number, the RPN level of uncertainty in failure mode.

NOTE: This RPN calculation differs from the method mentioned in Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA), IEC 60812

2.12 RUL – Remaining useful life, the time frame of a safe operation of wind turbine(s) or a wind farm.

2.13 SCADA – Supervisory control and data acquisition.

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2.14 WTG – Wind turbine generator

3 Units of Measurement

3.1 Values stated without parentheses are the requirement. Values in parentheses are explanatory or approximate information.

4 Undated References

4.1 Any undated reference to a code or standard appearing in the requirements of this Outline of Investigation shall be interpreted to the latest edition of that code or standard.

Table 4.1
Normative references

No.	Document number	Title
1	IEC 61400-1	Wind turbines – Part 1: Design requirements
2	IEC 61400-12-1	Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines
3	IEC 61400-22	Wind turbines – Part 22: Conformity testing and certification
4	ISO/IEC 17020	General criteria for the operation of various types of bodies performing inspection
5	ISO/IEC 17025	General requirements for the competence of testing and calibration laboratories
6	ISO/IEC 17065	Conformity assessment – Requirements for bodies certifying products, processes and services
7	ISO 13849	Safety of machinery – Safety related parts of control systems
8	GL	Guideline for the Certification of wind turbines
9	UL 6142	Small Wind Turbine Systems
10	UL 6141	Large Wind Turbine Systems
11	IEC 60812	Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)
12	IEC 61400-13	Wind turbines – Part 13: Measurement of mechanical loads
13	TR6	Technical Guidelines for Wind Turbines
14	MEASNET	Evaluation of Site-Specific Wind Conditions

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CONSTRUCTION

5 General

5.1 The process to establish a LTE strategy and risk shall follow the steps described in Table 5.1.

5.2 The LTE strategy shall be considered successful if the value of RPN is less than 50 for each failure mode.

Table 5.1
Procedure of LTE

Steps	Clause
Step 1: Requirement for external condition	6.2
Step 2: Requirement for operation condition	6.3
Step 3: Requirement for wind turbine model	6.4
Step 4: Requirement for remaining useful life	6.5
Step 5: Requirement for inspection	6.6
Step 6: LTE Risk Analysis	6.7

6 Requirements for life time extension

6.1 General

6.1.1 In order to extend the lifetime of a wind turbine based on RPN determination criteria, the wind turbine(s) in a wind farm shall comply with the requirements mentioned in Sections 6.2 – 6.7.

6.2 Step 1: Requirements for external conditions

6.2.1 Operational historical data of external conditions relevant to the structural loading of the wind turbine(s) in the wind farm shall be used.

6.2.2 To assist in determining site external conditions SCADA data, met mast data, and/or public databases may be used. The respective source shall be named.

6.2.3 To cover the seasonal variations in wind characteristics, the measurement period shall cover at least 12 months. The measurement device set-up except for the met mast location shall comply with Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines, IEC 61400-12-1. The on-site measurement location shall be chosen to achieve representative measurements for the wind turbine(s) under assessment.

6.2.4 The analysis of the measured data shall comply with Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines, IEC 61400-12-1 or other equivalent standard like MEASNET, as applicable.

6.2.5 The following information shall comply with the requirements outlined in IEC 61400 series.

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6.2.6.1 Site topography

a) Details of the site/ wind farm;

b) Details of the site lay-out and change in layout;

c) Wind farm layout coordinates

d) Neighboring wind farms in a radius of 20 rotor diameters (past and future)

e) Roughness map of the site in an area of 15 km around the site

f) Assessment of complexity; and

g) Assessment of obstacles.

6.2.6.2 Measurement equipment

a) Details of met mast;

b) Details of measurement equipment; and

c) Description of data logging.

6.2.6.3 Other information

a) Filtering and other data verification analysis;

b) Calibration details;

c) Details of the extrapolation models including the model validation;

d) Details of the wind modeling and uncertainties;

e) Historical changes to the site/forestation (tree growth or logging); and

f) Applicability of the measurements to past and future periods. In case of any possible changes to the site, these shall be considered in the extrapolation of data to future periods.

6.2.6.4 Wind speed and wind direction

a) General

1) The wind speed bin shall be 2 m/s bins or less;

2) Wind direction sector shall be 30 degrees or less; and

3) The wind speed shall be given as a 10 minute average.

b) Methods for long term assessment

1) The long term measurements from met station along with an appropriate co-relation technique (e.g. MCP) may be used; and

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2) The methods used for long term assessment shall comply with the Wind turbines – Part 1: Design requirements, IEC 61400-1, Technical Guideline for Wind Turbines, TR06, Evaluation of Site-Specific Wind Conditions, MEASNET.

6.2.6.5 Wind speed distribution

1) The probability distribution function shall comply with Wind turbines – Part 1: Design requirements, IEC 61400-1.

6.2.6.6 Turbulence

a) 10 minute average turbulence intensity values for each wind speed bin and each wind direction sector shall be used;

b) The wake induced turbulence intensity shall be accounted in the assessment. The methodology shall be compliant with Wind turbines – Part 1: Design requirements, IEC 61400-1; and

c) In case of a complex terrain, the site complexity shall be accounted in the turbulence intensity calculation.

6.2.6.7 Wind shear

a) The wind shear at the on-site measurements location shall be calculated using two (2) anemometers – with a minimum vertical spacing of 20 m. For complex terrains, the wind shear shall be derived for each wind turbine location based on flow modeling.

6.2.6.8 Density, temperature, pressure, and humidity

a) The minimum, maximum and mean values of density, temperature, air pressure, and humidity shall be used.

6.2.6.9 Flow inclination

a) The flow inclination angle shall be analyzed for each wind direction sector. For complex terrain reference shall be made to the IEC 61400-1.

6.2.6.10 Electrical conditions

a) The grid conditions of the site shall be evaluated for possible impact on the loads and performance of the wind turbines.

6.2.6.11 Other environmental conditions

a) Other environmental conditions with significant impact on the loads of the wind turbine like extreme temperatures, earth quake, icing, tornados or hurricanes shall be taken into account for the load evaluation or considered in the risk analysis. Special attention shall be given to geographical characteristics.

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6.3 Step 2: Requirements for operational conditions

6.3.1 Operational historical data of wind turbine(s) conditions relevant to the structural loading of the wind turbine(s) in the wind farm shall be characterized in accordance with the list of parameters in Appendix A1.

6.3.2 To assist in determining wind turbine(s) operational conditions the SCADA data and operational and maintenance records shall be used. The respective source shall be named.

6.3.3 To reduce the analytical effort wind turbines can be grouped in cells represented by one wind turbine. The selection criteria for the cell definition shall be specified.

6.3.4 The following information shall be evaluated as a part of the assessment:

6.3.4.1 General

a) Source of the data (e.g. SCADA, OEM records);

b) Material and software change logs;

c) Criteria for the selection of the representative wind turbine(s);

d) General description of the wind farm control and communication with the wind turbine controller; and

e) The operational data of the wind turbine(s) including the load relevant events.

6.3.4.2 Load relevant transient events

a) Transient events with significant impact on the loads of the wind turbine(s) like:

1) Emergency stops (E-stops) and stops triggered by the safety system;

2) Stops performed by control system;

3) Start ups;

4) Operation with yaw misalignment exceeding the design limits; or

5) Failure of wind turbine systems.

b) Wind speed at hub height and electrical power (and/or operating mode), at which the event has occurred;

c) Total number of events; and

d) Type/reason of event and typology of the braking program used to stop the wind turbine.

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6.3.4.3 Power production data

a) Power production distribution over time per turbine;

b) Cumulative power produced per turbine; and

c) Measured power curve based on SCADA data for the representative period/wind turbines.

6.3.4.4 Parked/idling data

a) Number of hours under idling condition;

b) Wind speeds and wind direction during parked condition; and

c) State of the wind turbine electrical supply during idling state.

6.3.4.5 Maintenance and repair data

a) Maintenance plan report and protocols;

b) Report of major damages to the wind turbine(s);

c) Report of replacements or repairs of components;

d) Special maintenance, if applicable; and

e) Inspection reports.

6.3.4.6 Grid related data on site

a) Annual number of network outages on the wind farm;

b) Fault ride through methodology (if present);

c) Voltage and frequency range related shut downs or disconnections;

d) Ramp rate or power factor related shut downs;

e) Corrections in the operating strategy for grid suitability; and

f) Other grid related shut downs.

6.3.4.7 Other data (if applicable to the site)

a) The applicability of the following special items for the possible impact on the loads and performance of the wind turbine shall be evaluated based on the outcome of the site conditions outlined in Section 6.2.

1) Number of hours of ice accretion;

2) Wind speed during the ice accretion;

3) Methodology for ice detection and reaction of the wind turbine;

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4) Mass of the ice on the blades and the approach used to determine the mass;

5) Potential influence of the wind farm controller on the operation of the wind turbine;

6) Earth quake;

7) Lightning strike;

8) Storm events; and

9) Other geographical characteristics

6.3.4.8 Control system related data

a) Description of the control system strategy (inputs, outputs, sensors, load reduction and operational strategies);

b) Current software version of the control system;

c) Report of the modifications in control system software and the deviation of the parameters or limits from the values considered in the design;

d) Modifications in pitch converters (if any);

e) Upgrade in the controller strategy; and

f) Other changes in control system or safety system related items of the wind turbine.

6.4 Step 3: Requirements for wind turbine model

6.4.1 Step 3 focuses on wind turbine simulation model generation and validation for applicability for LTE use. The list of parameters shall comply with Appendix A2.

6.4.2 The list of parameters to generate the simulation model shall include all of the attributes in Appendix A2.

6.4.2.1 The simulation model shall include the modification to the wind turbines during operational life e.g. change in controller parameters , if applicable.

6.4.2.2 The simulation model shall include the change in external environmental condition e.g. change in soil properties, if applicable.

6.4.3 For a simulation model that was validated in the course of a wind turbine type certification in accordance with Wind turbines – Part 22: conformity testing and certification , IEC 61400-22 or equivalent a prove of the validation shall be provided.

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6.4.4 For a simulation model that does not comply with 6.4.3. The model generation and validation shall comply with 6.4.4.1 – 6.4.4.5.

6.4.4.1 A detailed procedure of model generation including the data used to build up the wind turbine model (e.g. data sheets, manuals etc.) shall be evaluated in accordance with Wind turbines – Part 1: Design requirements, IEC 61400-1 or equivalent.

6.4.4.2 Model data validation.

6.4.4.3 Validation of aerodynamic model.

a) The aerodynamic model shall be validated by a comparison of the simulated and measured power curve including transfer function for the anemometer wind speed; and

b) Furthermore, a validation of the aerodynamic model (or the derived coefficients) by comparison of the assumed geometry with published data base shall be carried out.

6.4.4.4 Validation of structural model.

a) To validate the structure model, the 1st Eigen frequency of simulation and measurement shall be compared for tower and blade as a minimum.

b) The risk analysis mentioned in 6.7 shall capture the extent of the model data validation.

6.4.4.5 Load evaluation

a) LTE requires that the load simulation model is validated by load measurements. These measurements shall be made on a wind turbine that is similar to the wind turbine under consideration with respect to aerodynamics, control and dynamic response;

b) Input to the validated model shall comply with Section 6.2 and 6.3;

c) The model validation shall comply with Wind turbines – Part 13: Measurement of mechanical loads, IEC 61400-13;

d) Load time series generated from simulation shall be compared to MLC for relevant situations to confirm the dynamic behavior; and

e) DLCs fatigue loading level (including markov matrices and LDD) for the following component shall be compared to MLC:

1) Blade sections (if applicable);

2) Blade root;

3) Shaft (rotating and non-rotating);

4) Tower top;

5) Tower bottom;

6) Tower sections (if applicable).

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6.5 Step 4: Requirements for RUL (Remaining Useful Life)

6.5.1 The RUL of the wind farm is calculated by representative sample of wind turbines RUL in each cells.

6.5.2 The RUL of the wind turbine is defined by the minimum RUL of the individual components in the wind turbine.

6.5.3 The relevant loading level (DEL, LDD etc.) as per below equation shall be calculated to determine the remaining useful life of components. The RUL Criteria is calculated as shown below:

$$FL_{design} \geq FL_{consumed} + FL_{RUL}$$

6.5.4 The RUL for any critical components in respect to the structural integrity and the operational safety of the wind turbine shall be derived by comparison of site specific component load to their design load.

6.5.5 The load evaluation shall be based on the standard and the respective edition used as design standard of the wind turbine under assessment.

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6.6 Step 5: Requirements for the inspection

6.6.1 The representative wind turbine(s) used for the LTE shall be inspected for their critical components health condition and functioning. See Appendix A3 for a list of inspection criteria.

6.6.2 Further inspections shall be decided based on results from first round of inspections mentioned in 6.6.1.

6.6.3 The following components as a minimum shall be evaluated as a part of the inspection:

a) Over all wind turbine(s) condition;

b) Damages on the following components/systems;

1) Tower (sections) and foundation;

2) Blade;

3) Nacelle and hub;

4) Bolt connections;

5) Bearings;

6) Pitch system;

7) Yaw system;

8) Hydraulic systems;

9) Electrical systems; and

10) Gear box (through videoscopy if applicable).

c) Wind turbine operation;

d) Test of safety and control systems;

e) Test of all operating states;

f) Personnel safety aspects;

g) Maintenance logs (including the track of the controller, pitch system software); and

h) SCADA data for the correctness check of operational data provided as given in step 2.

6.6.4 The inspection as part of the LTE analysis shall take place not earlier than one year before the date the LTE analysis is based on.

6.7 Step 6: Risk analysis

6.7.1 General

6.7.1.1 A risk analysis shall be performed to identify uncertainties in the calculation of the remaining useful life time.

6.7.1.2 Since the process of calculating the RUL is subjected to the uncertainty; accuracy of simulation data shall be taken into account to derive the safe operation of wind farm based on RUL.

6.7.1.3 All steps to calculate the RUL shall be considered in the risk analysis.

6.7.1.4 The failure mode shall be derived based on the important steps considered from Step 1 to Step 6.

6.7.1.5 Based on wind farm history and operation condition relevant failure modes shall be derived.

6.7.1.6 A justification to decrease the severity level or increase the confidence level on accuracy shall be summarized in a report.

6.7.1.7 Operational safety, structural integrity and the personnel safety shall comply with Wind turbines – Part 22: Conformity Testing and Certification, IEC 61400-22.

6.7.1.8 A justification of conditions for extended operation of the wind turbine based on risk analysis shall be developed by the applicant. This may include but not only limited to replacements of any wind turbine components, modifications in the operating strategy (e.g. de-rating, curtailment), repair, inspections/maintenance details and software updates.

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6.7.2 Risk analysis procedure

6.7.2.1 A failure mode shall be derived for the site according to 6.7.1.4, as a minimum the considered failure mode shall comply with Appendix A4.

6.7.2.2 Severity level in the scale of 1 – 10 for each failure mode shall be assigned by the applicant, the severity is defined by the level of impact of failure mode to overall RUL; where 1 is lowest and 10 is highest.

6.7.2.3 Confidence level on accuracy in the scale of 1 – 10 for each failure mode shall be assigned by the applicant, the confidence level defines how accurate the real site condition is mapped into simulation model; only level 1, 5 and 10 shall be chosen where 1 is highest and 10 is lowest.

6.7.2.4 The final RPN number is calculated as follows:

$$\text{RPN} = (\text{Severity}) \times (\text{Confidence Level})$$

6.7.2.5 A risk analysis shall be carried out to identify uncertainties in the calculation of the remaining useful life time. The risk analysis shall include the determination of consequences of each risk on the RUL (impact on the RUL). In addition, preventive and detection measures shall be specified, if applicable.

6.7.5 Risk criteria

6.7.5.1 The RPN number defines the confidence level on input used to derive the RUL, RPN shall be less than 50 for any failure mode.

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Appendix A

A1 Wind turbine control parameters & settings

Control related parameters		
Parameter Group	**Parameter**	**Unit**
Rotor speed referred to LSS or HSS	Gearbox ratio	–
	Operating rotor speed range (cut in - cut out)	1/min
	Rated rotor speed set value for the controller	1/min
	Cut-out rotor speed limit for the control system	1/min
	Activation speed limit for the safety system	1/min
	Maximum allowable generator speed	1/min
Electrical power output and torque	Rated electrical power output	kW
	Over-power limit for the control system	kW
	Slip torque of slip coupling incl. tolerance	kNm
	Maximum generator torque during short circuit	kNm
Operational wind speed limits	Cut-out wind speed	m/s
	Short-term cut-out wind speed	m/s
Mechanical brake	Minimum required / maximum braking torque	kNm
	Maximum braking moment	Nm
	Ramp time (time constant) for braking torque	s
Aerodynamic brake, pitch system	Minimum/maximum pitch or blade-tip angle (hardware stop)	°
	Pitch angle after normal stop / grid loss	°
	Maximum allowable difference between pitch angles of blades	°
	Maximum pitch-/ tip-speed at emergency stop	°/s
	Maximum pitch speed during operation	°/s
Wind tracking	Minimum/maximum yaw-braking torque	kNm
	Uninterruptible power supply (UPS) for yaw system	yes / no
Temperature	Minimum/maximum ambient temperature during operation	°C
Nacelle vibration	Maximum acceleration limit for the control system limits	m/s^2

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Control related parameters		
Parameter Group	**Parameter**	**Unit**
Controller parameters	Gains, delays used in the PLC software	
	Averaging times, schedules etc. related to the control algorithms	

A2 Simulation model parameters (Onshore)

Simulation model parameters (Onshore)		
Parameter Group	**Parameter**	**Unit**
Blade	Bending stiffness for the sections of the blade in flap and edge directions.	Nm/rad
	Mass per unit length	kg/m
	Logarithmic damping decrements for the first and second Eigen modes in flap and edge directions.	–
	Aerodynamic coefficients of the blade airfoils. Lift, drag and moment coefficients as a function of the angle of attack	–
	Distance between pitch axis and the aerodynamic center of the airfoil.	%
	Twist angles along the blade	°
	Chord length along the blade	m
	Prebending in flap and edge direction	m
	Deviation of the mass	%
	Maximum pitch angle error related to the 0° blade position, due to manufacturing and mounting tolerances	°
Hub	Mass (including pitch drive and pitch bearing)	kg
	Mass Inertia in x-, y- and z- axis	kg m^2
	Drag coefficients (Hub Cover: front & side)	
	Hub cover area (front and side)	m^2
Main Shaft	Drive train bending stiffness in x-, y- directions	Nm^2
	Torsional stiffness	Nm/rad

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Simulation model parameters (Onshore)		
Parameter Group	**Parameter**	**Unit**
Nacelle	Rotor Overhang (horizontal Distance: Hub Center –tower axis)	m
	Mass Moments of inertia for x-, y- and z-axis	kg m^2
	Bending stiffness at yaw bearing	Nm/rad
	Rotor tilt and cone angle	°
	Distance: hub center – main bearing	m
	Distance: hub center – main shaft flange	m
	Distance: the nacelle center of gravity – tower top center for x-, y-, z-axis	m
	Distance: Azimut – Rotor axis (vertical)	m
	Nacelle cover area (front & side)	m^2
	Drag coefficients (nacelle cover: front & side)	–
	Coordinates of the center of pressure on the nacelle cover (front & side)	m
Tower	Stiffness distribution along the tower	–
	Mass distribution along the tower	–
	Point Masses representing e.g. equipment inside the tower.	kg
	Logarithmic damping decrements for the tower bending modes.	–
	Drag coefficient	–
Foundation	Mass of the foundation	kg
	Mass Moments of inertia for x-, y- and z-axis.	kg m^2
	Stiffness (rotational & translational for x-, y- and z- axis)	Nm/rad N/m
	Damping coefficient	–
Generator and Power System	Electrical and mechanical power losses for 0%, 50% and 100% of the nominal power	kW
	Generator Short circuit torque moment	Nm
	Generator mass moment of inertia	kgm^2
	Generator mass	kg
Yaw system	Ramp time (time constant) for reaching the nominal yaw rate	s
	Nominal yaw rate	°/s
Pitch system	Maximum pitch acceleration n	$°/s^2$
	Maximum pitch rate	°/s
Drive Train	Mass moment of inertia along the rotational axis	kg m^2
	Bending stiffness	Nm/rad
	Torsional stiffness	Nm/rad
	Logarithmic damping decrement	–

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