IECRE OD-551-13

Edition 1.0 2016-02-26

IECRE OPERATIONAL DOCUMENT

IEC System for Certification to Standards relating to Equipment for use in Renewable Energy applications (IECRE System)

Measurement of mechanical loads of electricity producing wind turbines

IECRE OD-551-13:2016(EN)

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Measurement of mechanical loads of electricity producing wind turbines

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

PRICE CODE ZZ

CONTENTS

1 Introduction

This OD covers the assessment of a mechanical load measurement test for Test Laboratories who want to get this competence area recognised under IECRE.

Specifically, this OD covers the standard assessment as per the W E -OMC Rules of Procedure. The scope of this OD is the IEC 61400-13 standard.

This scope is referenced in this OD as 'the standard'.

The standard assessment is based on four elements:

– A review of three reports issued by the Applicant within the last three years
– Successful participation in a mechanical load measurement proficiency test
– Review of key internal procedures

In this document, the Applicant is the organisation asking for an assessment according to this OD. The applicant may be an already recognised RETL or an organisation not yet recognised under IECRE for this competence area. An RETL refers to an IECRE recognised Test Laboratory.

2 Review of reports issued

In order to have three reports reviewed, the Applicant shall submit an overview of reports submitted the last three years with the IECRE logo. In case the assessment is for a candidate RETL or the Applicant has issued fewer than three IECRE test reports for power performance testing , the Applicant shall submit to the IECRE Secretariat a list of reports issued that state compliance with the standard.

The Lead Assessor, together with the Technical Assessors and/or experts, shall select from this list three reports. These reports have to be submitted to the IECRE Secretariat by the Applicant.

The reports shall be reviewed for compliance with the standard , as per the checklist in Annex A of this OD. A filled-out version of the check list shall be included in the final assessment report.

3 Proficiency testing

3.1 Topics of proficiency testing

The following aspects of the mechanical load test shall be covered by the proficiency test and the results from multiple test laboratories shall be compared. For each entry the number of results where a comparison shall be done, documented and reported is indicated.

a) Capture matrices/data filtering
b) Calibration of the load sensors
c) Statistical results
d) Rainflow counting
e) LEQ
f) Load spectra
g) Dynamics analysis

3.2 Strategy of proficiency testing

Proficiency test should follow the “2 step approach”:

– The goal of step 1 is to test the underlying standard and to create clarification sheets
– The goal of step 2 is to test the capability of the participating institutes to follow procedures according to the standards and their respective clarification sheets

The coordinator of the proficiency test has to have know how on performing proficiency tests in general and has to have know how on the topic of the proficiency test.

All further requirements for proficiency tests under IECRE will be described in a respective document.

4 Review of internal procedures

4.1 Identification of key procedures

The following procedures should normally be checked:

– Test plan prior to start of campaign
– Identification of the turbine under test
– Test requirements
– Instrumentation
– Determination of calibration factors
– Data verification
– Processing of measured data
– Uncertainty estimation
– Minimum test report results

Details on these key procedures can be found in the respective table below.

5 Inspection of field test

As part of the assessment the assessment team shall inspect one test in the field to establish if a nearby test site is available. If not, the test lab has to provide the needed information in form of photo - and written documentation.

a) Compliance with the standard
b) Compliance with the key internal procedures as defined under section 4 of this OD
c) Identify further process or technical issues that could affect the result of the test

6 Checklist

Please note that this checklist is used for reviewing reports as well as the applicant's internal procedures and may be used as well for the on-site inspection

6.1 Test plan prior to start of campaign

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
	Safety during testing	On this basis, such tests shall be initiated and observed from a safe position, usually at a certain distance upwind of the rotor plane and they should 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.	– Are there personal safety requirements, prior to the test?		
	Procedure for operation		– Is there a procedure for manually triggered MLCs (measurement load cases) – Is there a procedure for installation?		

6.2 Identification of the turbine under test

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
	Reporting clause 12.1)	1) Introduction including: a) Test objective b) Test period	– Check that both points mentioned in 12.1) have been included in the report – Check that the test period is covered by the validation periods of calibration certificates		
	Reporting clause 12.2)	2) An identification and description of the specific wind turbine configuration under test: a) turbine make, type, serial n umber, production year; b) rotor diameter; c) rotor speed or rotor speed range; d) blade data: make, type, serial numbers, number of blades, fixed or variable pitch, and pitch angle(s), presence of vortex generators, stall strips, serrated trailing edges etc; e) Hub height and tower type; f) Description of control system (device and software version) g) Photograph of test turbine h) Any changes made to the test turbine during the test period;	– Are the wind turbine main characteristics documented according to 12.2) from a) to h) – Is it documented how that information is obtained (manufacturer's certificate, in -situ verification,..)? – Check that all points mentioned in 12.2) have been included in the report		

6.3 Test requirements

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
	6 Test requirements 6.1 General	In Clause 6 the requirements for the test are described. These include requirements for • The test site, • The MLCs and the amount of data required for each, • The quantities to be measured, and • Changes in the turbine configuration.	- Have there been specific test conditions worth mentioning, such as snow and ice (which may affect turbine and sensors), freezing weather (affecting the sensors and cup classification), strong hail - To the extent these are measured, also information regarding shear, veer and upflow is to be reported alongside turbulence		
	6.2 Test site requirements	The terrain and wind conditions shall be capable of fulfilling the requirements of the capture matrix.	- Is there an evaluation for the test campaign prior to the test?		
		An obstacle assessment and terrain assessment shall be completed per IEC 61400- 12-1.	- Check relating to the measurement sector shall be on the basis of OD-551-12		
		The measurement sector can be expanded beyond the one found using the methods in IEC 61400-12-1 if it can be shown that the wind speed and TI measured at the meteorological mast are representative of those seen by the wind turbine (e.g. turbine and meteorological mast on ridge).	- If the measurement sector is expanded, check that evidence showing such representativeness is provided and reported.		
		If the test site does not meet the requirements of IEC 61400-12-1, a site calibration should be performed.	- Checks relating to the assessment of the test site shall be on the basis of OD-551-12		
			- If no site calibration is performed in complex terrain, is the extra uncertainty considered and reported?		
	Reporting clause 12.3)	1) A description of the test site, including a) Photographs of all measurement sectors preferable taken from the wind turbine at hub height b) Geographical location with sufficiently detailed information to allow the reader to locate the test machine. c) Test site map showing the surrounding area covering a radial distance of at least 20 times the wind turbine rotor diameter and indicating the topography, location of the wind turbine, meteorological mast, significant obstacles, other wind turbines and measurement sector. d) If the measurement sector is expanded beyond the one found using the methods in the IEC 61400-12-1 provide evidence that shows that the wind speed and TI measured at the meteorological tower are	- Check that all points mentioned in 12.3) have been included in the report		

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
		representative of those seen by the wind turbine. e) If site calibration is performed, the site calibration results including the limits of the final measurement sector and the rationale for any changes from the results of the site assessment.			
	6.3 Measurement load cases 6.3.2 MLCs during steady-state operation	6.3.2.1 power production During power production, measurements shall be performed between cut-in and to cut-out or vr+4 m/s (depending on turbine configuration) (see Table 4 and Table 5).	No specific guidance		
		6.3.2.2: Parked The loads on the parked wind turbine shall be measured.	No specific guidance		
	6.3.3 MLCs during transient events	6.3.3.1: Start-up This MLC 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 at cut-in wind speed and at a wind speed greater than 2 m/s above rated wind speed. If the turbine operates at more than one fixed speed, cut-in on the different rotational speeds shall be evaluated also.	No specific guidance		
		6.3.3.2: Normal shutdown 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 parked condition. The normal shutdown shall be performed at cut-in wind speed, at rated wind speed and above rated wind speed.	No specific guidance		
		6.3.3.3: Emergency shutdown The loads during an emergency shutdown shall be considered. This shutdown shall be performed at/above rated power.	No specific guidance		
		6.3.3.4: Grid failure The loads during a grid failure shall be considered. This MLC shall be performed while the turbine is producing rated power, by removing external power to the wind turbine resulting in a shutdown.	No specific guidance		

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
	6.3.4 MLCs for dynamic characterization	Table 3 provides the measurement load cases that are recommended for the dynamic characterization.	- If the dynamic analysis is not derived exactly from the MLCs in Table 3, is there any clarification for the selection of MLCs?		
	6.3.5 Capture matrices	6.3.5.2: Power production Table 4 shall be used for stall controlled (both passive and active) wind turbines. Table 5 shall be used for all turbines that are not stall controlled (such as pitch to feather).	- Is ten minute average wind direction inside the measurement sector? - Are all mandatory signals in Table 9, Table 11 and Table 12 classified in the capture matrices (Table 4 or Table 5) valid, for example after filtering? - Was data recorded under abnormal conditions (turbine or environmental, such as ice on the blades or an extreme direction change in the wind)? - Is data of produce power for full ten minute period used? -		
			- Is the dataset sufficient according to the requirements in Table 4 or Table 5, depending on the tested wind turbine configuration? -		
		6.3.5.3: Parked One time series shall be collected with target values of 30° yaw misalignment, one with 0° yaw misalignment and one with –30° yaw misalignment (see Table 6).	- Is the dataset sufficient according to the requirements in Table 6? - Is the date or data sample in the parked capture matrix documented?		
		6.3.5.4: Transient events The capture matrices for the transient events are given in Table 7 and Table 8. The minimum number of repetitions and the wind speed range are indicated in Table 7. The wind speed is the wind speed at the beginning of the transient event. The emergency shutdown and grid failure shall be performed at rated power.	- Is the dataset sufficient according to the requirements in Table 7 and Table 8? - Is the date or data sample in the transient capture matrices documented?		
	6.4 Quantities to be measured	Mandatory and recommended measurements as listed in Table 9, Table 10, Table 11 and Table 12 are found to be necessary for model validation.	- Are the mandatory measurements as listed in Table 9, Table 10, Table 11 and Table 12 tested?		
	Reporting clause 12.4)	2) Channel list	- Are the mandatory measurements as listed in Table 9, Table 10, Table 11 and Table 12 reported?		
	Reporting clause 12.5)	3) Coordinate system used for the test	- Is the coordinate system for the measurement quantities clearly described in the test report?		

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
	6.5 Turbine configuration changes	Any change that has been made to the turbine shall be reported by the manufacturer and shall be included in the test report.	- Are the changes, if any, reported by the manufacturer and included in the test report? -		
		The manufacturer shall classify the changes into the following categories: 1) Changes without any significant impact on loads Data from before and after the change can be used within the same database 2) Changes with significant impact on loads a) Temporary changes: this data shall be excluded from the database b) Persistent changes, even though they can be cross-simulated with the same simulation model after implementation of the same change in the model. These periods shall be segregated into a separate database. c) Changes that resolve a problem and actually bring the turbine into the state it should have been in before. This shall result in a re-start of the campaign	- Are the changes classified as per the requirements? - If the changes have been found significantly load impacting, is there an appropriate way to deal with that?		
		The capture matrix requirements (see 6.3.5) shall be fulfilled with at least one configuration where no changes are made with significant impact on loads.	No specific guidance		

6.4 Instrumentation

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
11	7.1 Load quantities 7.1.1 Types of sensors	For wind turbines, it will seldom be possible to place a load cell in a main load path. For this reason, strain gauges applied to the structure are selected as the recommended type of sensor and thus the following subclasses focus on the use of electrical strain gauges. If alternative load sensors are used the requirements shall be adjusted accordingly.	No specific guidance		
	7.1.2 Choice of sensor location		- Are the positions of load sensors, with clear words and photographs showing the reference position, documented and reported?		
	7.1.3 Measurement of blade root bending moments	Flapwise and edgewise bending moments shall be measured. Regardless of the mounting location, cross-sensitivity shall be measured, and shall be addressed (i.e. through correction or increased uncertainty).	No specific guidance		
	7.1.4 Blade bending moment distribution	Blade bending moment distribution can be measured using additional sets of strain gauges located at a cross section at least 30% or as far as practically possible up to 50% of rotor radius. Other requirements from 7.1.2 and 7.1.3 also apply. For the bending moment distribution the used coordinate system shall be clearly defined.	- Is the coordinate system clearly defined for the bending moment distribution?		
	7.1.5 Blade torsion frequency/damping	The blade first torsional frequency and damping can be estimated using strain measured with a half or full torsion strain-gauge bridge through operational modal analysis. Since neither the frequency nor the damping rely on absolute magnitude of the measurement, no calibration of this signal is required.	No specific guidance		
	7.1.6 Measurement of rotor yaw and tilt moment	Asymmetrical rotor loads shall be measured on the primary load path as close to the rotor as possible. On some machines, it may not be possible to apply strain gauges to the shaft. In such cases, it is required to install gauges for bending moments in the non-rotating system, either on the shaft-support or tower top	No specific guidance		
	7.1.7 Measurement of the rotor torque	The strain gauges for measuring the torque of the main shaft shall consist of a full bridge with pairs of gauges on opposite sides of the shaft. If torque measurements on the shaft are not possible, tower top bending gauges and nacelle yaw position are permitted. Power and rotor speed shall not be used as a substitute to measure rotor torque.	- Check that the torque of the main shaft is directly measured by load sensors.		

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
	7.1.8 Measurement of tower base bending	The bending moments at the tower base shall be measured in two perpendicular directions for a tubular tower. Tower base bending moments shall be measured using full strain gauge bridges mounted in the lower 20% of the tower height as close to the base flange as possible while avoiding disturbances from load introduction effects for the base flange, door, etc. As a rule of thumb, tower base gauges should be placed at least one tower diameter from any flange.	No specific guidance		
	7.1.9 Tower top bending moments	Tower top bending moments shall be measured using full strain gauge bridges mounted in the top 20% of the tower as close to the tower top as possible while avoiding disturbances from load introduction effects. As a rule of thumb, tower top gauges should be placed at least one tower top diameter below the tower top flange. If tower top bending moments are used to derive rotor torque and rotor tilt moment, the bending moment shall be measured as high up as reliable measurements can be taken	No specific guidance		
	7.1.10 Tower mid bending moments	Tower mid bending moments should be measured using full strain gauge bridges mounted in between 30 % and 70 % of the tower height. Caution should be taken to either take measurements one tower diameter away from any tower flange or address the effects from the flange on the measurements such stress concentrations or constraining thermal expansion of the tower wall material.	No specific guidance		
	7.1.11 Tower torque	Tower torque shall be measured using full strain gauge bridges mounted in the top 20% of the tower as close to the tower top as possible while avoiding disturbances from load introduction effects. As a rule of thumb, tower top gauges should be placed at least one tower top diameter below the tower top flange.	No specific guidance		
	7.1.12 Tower top acceleration	Accelerometers should be used for measurement of tower top acceleration. The accelerometers shall be mounted on that part of the nacelle that yaws with the rotor. Care should be taken when selecting the accelerometers to account for their low-frequency phase shift and amplitude characteristics.	No specific guidance		
	7.1.13 Pitch actuation loads (on hub side of pitch bearing)	The load (torque or force) that actuates the blade pitch shall be measured on the hub side of the pitch bearing. The load can be measured directly (i.e., strain gauges or load cells) or indirectly (i.e., actuator electric	No specific guidance		

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
		power and rpm or hydraulic pressure).			
	7.2 Meteorological quantities 7.2.1 Measurement and installation requirements	The requirements given in IEC 61400-12-1 shall be followed for the measurement and installation of all meteorological quantities. Turbulence intensity is defined as if measured through a hub height anemometer (sonic or cup). If other wind speed sensing techniques are used, the derived TI shall be equivalent to that measured by either a sonic or cup anemometer.	- Checks relating to the measurement and installation of all meteorological quantities shall be on the basis of OD-551-12		
	7.2.2 Icing potential	Icing potential can be measured through measurement of air temperature by itself or possibly combined with a measurement of relative humidity.	No specific guidance		
	7.2.3 Atmospheric stability	The atmospheric stability can be measured by the difference between two vertically separated temperature measurements in addition to vertical wind shear measurement. As the temperature difference is small it preferred to measure the temperature difference directly instead of measuring two temperatures independently.	No specific guidance		
	7.3 Wind turbine operation quantities 7.3.1 Electrical power	The turbine’s electrical power output can be measured at any point as long as it properly described, measuring it in compliance with the IEC 61400-12-1 is recommended. Output from the wind turbine controller is acceptable.	No specific guidance		
	7.3.2 Rotor speed or generator speed	Rotor speed can be measured on either the low-speed shaft or high-speed shaft. If rotor speed is measured on the low-speed shaft, additional consideration should be given to achieve a sufficiently high speed resolution. If rotor velocity is measured on the high-speed shaft, additional consideration should be given to assure the sample rate is high enough to acquire the signal. Output from the wind turbine controller is acceptable.	No specific guidance		
	7.3.3 Yaw misalignment	Yaw misalignment shall be derived from wind direction and yaw position. Yaw position can come from the controller only if calibration verifications are performed regularly. Caution should be used on the 360° - 0° transition and the location of the dead band, if present. Other measurement techniques may be used, when it is documented that the accuracy and uncertainty of the measurement technique is equivalent or better to the measurement determined from wind direction and yaw position.	- Is the average derived correctly when the time series is on the 360° - 0° transition?		

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
	7.3.4 Rotor azimuth angle	Rotor azimuth angle shall be measured on the low-speed shaft, high-speed shaft (with reset on the low speed shaft) or provided by the wind turbine controller. If the controller signal is used, the latency shall be evaluated and addressed. Caution should be used on the 360° - 0° transition.	- Is the average derived correctly when the time series is on the 360° - 0° transition?		
	7.3.5 Pitch position	Blade pitch angle shall be measured directly by an encoder or provided by the wind turbine controller. If the controller signal is used, the latency shall be evaluated and addressed.	No specific guidance		
	7.3.6 Pitch speed	The pitch speed shall be measured either directly or derived from pitch position during post-processing of the data.	No specific guidance		
	7.3.7 Brake moment	How the brake moment is best measured depends on the turbine configuration. Examples are, verifying brake pressure (hydraulic or spring pressure) with assumed coefficient of friction, measuring on the torque reaction arm, by measuring shaft torque on both sides of the brake or through analysis of deceleration time.	No specific guidance		
	7.3.8 Wind turbine status	Wind turbine status can be measured using controller signals (i.e., grid connection, emergency shutdown, protection system activation)	No specific guidance		
	7.3.9 Brake status	Brake status shall be measured, either directly (i.e., proximity sensor) or indirectly (brake pressure or turbine controller; in which case latency needs to be evaluated).	No specific guidance		
	7.4 Data acquisition system 7.4.1 General Annex G		- Is the range for all channels set properly (no clipping, sufficient resolution)? - If different data acquisition systems are used, is a synchronization procedure implemented, and is the error evaluated.		
	7.4.2 Resolution	For the measurement of mechanical loads on wind turbines the DAS shall have a minimum resolution of 12 bits in the A/D converter.	No specific guidance		
	7.4.3 Anti-aliasing	The DAS shall have aliasing protection on all load channels.	No specific guidance		

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
	Reporting clause 12.6)	4) Instrumentation a) Description of data acquisition system (A/D resolution, sample rate, filters, synchronization if applicable) b) For each channel: i. Details of instrumentation (make, model, serial number) ii. Details on signal conditioning iii. For each instrument, its actual location and orientation, mounting details iv. The slope, offset, their derivation method and calculation. v. Calibration data (actual measured data or calibration sheet cover page, end to end checks); for loads channels also the inputs used for the calibration and their sources (e.g. manufacturer or measured) vi. Any changes made to the instrumentation or calibration during the test period covered in the report.	- Check that all points mentioned in 12.6) have been included in the report		

6.5 Determination of calibration factors

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
	8.1 General		- Are all elements of the measurement chain calibrated?		
	8.2 Calibration of load channels		- Are the applied calibration methods for each load channel able to determine both the slope and offset?		
	8.2.1 General	All calibrations shall be conducted at low wind speeds in order to minimize aerodynamic loading of the wind turbine and at low and steady rotational speed in order to minimize inertia effects and aerodynamic forces.	- Are the calibrations conducted at low wind speeds and at steady rotational speed? - Are the environment and turbine status data during calibration recorded?		
		In the case the gravity loads are used for calibration of a load sensor, the information used to derive the applied loads shall be provided by the manufacturer.	- Is the information provided by manufacturer and documented?		
	8.2.2 Blade bending moments	In general, the analytical calibration is not feasible for calibration of the blade bending moments as the material properties are not well known.	- Is the calibration approach mentioned in the test report? - Does the calibration approach lead to reliable result? - Is there another approach to check the calibration result?		
			- If gravity loads are applied, how is the information of the blade mass and mass centre obtained (e.g. from the nameplate of the blade, from the designer, etc.)? - If the external load is applied, how are the applied moment derived?		
			- Is the crosstalk correction made for the blade load calibration?		
	8.2.3 Main shaft moments	An analytical calibration can be performed on shafts with near constant cross sectional properties and thus only for areas with minor stress concentration factors.	- Is the calibration approach mentioned in the test report? - Does the calibration approach lead to reliable result? - Is there another approach to check the calibration result?		
			- If an analytical calibration is used, where is the information of the cross section and geometry and material properties obtained?		
			- If gravity loads are applied, how is the information of the rotor mass and mass centre obtained (e.g. from the CAD model, from hoisting, etc.)? - If the external load is applied, how are the applied moment derived?		
		Besides the earlier mentioned methods of applying an external load or performing an analytical calibration, the rotor torque can also be calibrated by measuring power output and rotor speed, taking the drive train efficiency and the turbine's power consumption into account.	- If the slope is determined via the relation between power and rotor speed, is the loss in the drive train and generator considered? - Where does this data come from?		

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
	8.2.4 Tower bending moments	At the tower bottom the gravity moment is usually too small in comparison to the operational loads to be used for calibration. In that case the method shall only serve for verification of the calibration	- Is the calibration approach mentioned in the test report? - Does the calibration approach lead to reliable result? - Is there another approach to check the calibration result?		
			- If an analytical calibration is used, where is the information of the cross section and geometry and material properties obtained?		
			- If gravity loads are applied, how is the information of the tower head mass and mass centre obtained (e.g. from the CAD model, from hoisting and etc.)? - If the external load is applied, how are the applied moment derived?		
	8.2.5 Tower torque		- Is the calibration approach mentioned in the test report? - Does the calibration approach lead to reliable result? - Is there another approach to check the calibration result?		
			- If the external load is applied, how are the applied moment derived?		
	8.3 Calibration of non-load channels 8.3.1 Pitch angle	Calibration of pitch angle is performed relative to a reference mark at the blade root (normally 0°), which can also be used as a reference for placing the blade bending sensors. All instrumented blades shall be pitched to at least 2 well defined positions at which the signal output and true angle can be correlated. The two positions should at least be 80° apart from each other. Calibration of the reference mark to a physical origin should be performed as well or alternatively this shall be traceable through documentation. If the pitch angle is measured through the turbine controller, checks shall be performed regularly to verify the slope and offset.	No specific guidance		

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
	8.3.2 Rotor azimuth angle	The slope of the signal is typically derived by performing a few slow shaft rotations and scaling the signal range of the saw tooth shaped signal or number of pulses to match the 360 degree range or counting the number of pulses in a rotor revolution. For the derivation of the offset a few methods are available using: • a level on a defined surface on the shaft or hub, • an inclinometer on a defined surface on the shaft or hub, • rotor azimuth positions defined by applying the rotor lock, • the blade bending moment signals and looking for the location of the maxima and minima during a slow rotor rotation.	- Is the rotor azimuth position defined?		
	8.3.3 Yaw angle	The yaw position of the nacelle can be calibrated by pointing the main shaft (which is often aligned with the nacelle) at distant landmarks and using the coordinates of the landmark and the wind turbine to calculate the bearing of the rotor. Care should be taken when using a magnetic compass. The same external reference and method (e.g. landmarks using map, landmarks using a global navigation satellite system magnetic north) and the same coordinate system shall be used for the calibration of wind direction and yaw angle	- Is yaw angle and wind direction calibrated with the same coordinate system? - Is the process documented?		
	8.3.4 Wind direction	The wind direction can be calibrated by pointing the wind vane at distant landmarks and using the coordinates of the landmark and the wind vane to calculate the bearing of the vane, or by aligning the vane to the boom and determining the direction of the boom after final installation. Care should be taken when using a magnetic compass. The same external reference and method (e.g. landmarks using map, landmarks using a global navigation satellite system, magnetic north) and the same coordinate system shall be used for the calibration of wind direction and yaw angle.	- Is yaw angle and wind direction calibrated with the same coordinate system? - Is the process documented?		

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
	8.3.5 Pitch actuation loads	The calibration method of pitch actuation loads depends on the method used to measure it. If the load is measured through: • strain gauges, an analytical calibration shall be used for the derivation of the sensitivity. For derivation of the offset value measurements shall be taken in low wind conditions with the turbine at a standstill and the blade pointing vertically down. • current, calibrated instruments shall be used for the sensitivity and offset. 1106 • pressure, calibrated instruments shall be used in combination with the actuator geometry for derivation of sensitivity and offset. • controller signals: the sensitivity used by the controller shall be used. The offset value shall be derived in low winds, with the turbine at a standstill and the blade vertically down.	No specific guidance		
	8.3.6 Brake moment	The calibration method for the brake moment depends on the method used to measure it. If the load is measured through: • strain gauges, an analytical calibration shall be used for the derivation of the sensitivity. For derivation of the offset value measurements shall be used when the brake is not applied. • pressure, calibrated instruments shall be used in combination with an assumed coefficient of friction	No specific guidance		

6.6 Data verification

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
	Clause 9.1 General	The validity of the measured quantities as well as of the calculated quantities, for example, the resulting rotor loads from shaft bending moment measurements, shall be checked in order to exclude any erroneous recordings. Only valid data shall be used in further analysis. In general, data shall be rejected if they do not meet criteria related to sensor calibration, sensor operational ranges and noise. Any data filter or rejection criteria shall be clearly documented in the load measurement report.	- Is it documented under what conditions data is excluded from further analysis? - Is this fair and in compliance with the standard?		
		During the measurement period, data shall be periodically checked in order to ensure high quality and repeatability of the test results.	- Is there a log or any other form of document for regular data check?		
	9.2 Verification checks	Subclause 9.2 provides requirements and recommendation of verification checks that can be used to fulfill the data verification requirements.	- Is validation done for each of the following channels: • Wind speed • Wind direction • Temperature • Pressure • Power • Turbine status • Blade bending moments with main shaft torque • Main shaft moments with tower top moments • Tower moments at low wind speed and yaw rotation		
	Reporting Clause 12.7)	5) Data verification checks per requirements of 9.1.	- Check that this part mentioned in 12.7) has been included in the report		
	Reporting Clause 12.8)	6) Data rejection criteria (measurement sector, turbine status signals) Data classification (criteria for data to go in different capture matrices)	- Check that this part mentioned in 12.8) has been included in the report		

6.7 Processing of measured data

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
	10.1 General	Clause 10 describes the post processing requirements used to derive the results that shall be reported. Specifically, the following are discussed: time series analysis, summary load statistics, load spectra based on rainflow counted ranges and estimation of equivalent loads.	- If automated analysis tools are used. Is the software version controlled?		
	10.2 Fundamental load quantities	For the fundamental load quantities (Table 9), the following shall be computed for all normal operation data sets: • The 10-minute file statistics (minimum, maximum, mean and standard deviation) • The binned 10-minute statistics for each wind speed bin of the capture matrix. • The 10-minute damage equivalent load for a single fatigue exponent • The cumulative rainflow spectrum for all normal operation data sets	No specific guidance		
	10.3 Load quantities for larger turbines	For turbines with a rated power output greater than 1 500 kW and rotor diameter greater than 75 m, the additional measurement quantities in Table 10 also need to be post-processed. For the additional load quantities, the required analysis from 10.2 shall be applied. The non-load quantities such as blade torsional frequency and damping, tower top normal (also commonly referred to as fore-aft or downwind) acceleration and tower top lateral (also commonly referred to as side-to-side or crosswind) acceleration are concerned mainly with dynamics, so post-processing may be limited to: • The 10-minute standard deviation of the signal • The mean of the binned 10-minute standard deviations for each wind speed bin of the capture matrix • The identification of turbine natural frequencies using PSD of example data sets during operation/idling/transient event.	No specific guidance		

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
	10.4 Wind speed trend detection	Trended data sets shall not be rejected, nor shall the wind speed be de-trended. Parameters indicating the degree of wind speed trending shall be reported.	No specific guidance		Also check against Clause 6.
	10.5 Statistics	For each ten minute file the ten minute statistics (mean, maximum, minimum and standard deviation) shall be calculated for all signals.	No specific guidance		
	10.6 Rainflow counting	To determine damage equivalent loads (DEL) and the cumulative rainflow spectra, the load quantity time series shall be rainflow counted. For this standard only the ranges shall be used and means shall be ignored in further post processing. The used method shall be clearly reported along with the used parameters including: • Reference to the applied rainflow cycle counting method, • number of used range bins, • use and value of minimum range threshold. The number of divisions of the load range shall be at least 100 in order to achieve sufficient resolution. Remaining half cycles shall be counted as 0,5.	- Is the parameter for rainflow counting reported?		
	10.7 Cumulative rainflow spectrum	The rainflow cycle counts of individual 10-minute records shall be assembled to form a single cumulative rainflow spectrum for power production for each load quantity. The cumulative rainflow spectrum is determined by summing all the individual rain flow cycle counts of each file in the power production capture matrix. This spectrum is not intended to estimate the fatigue life of the turbine, thus no wind speed or turbulence weighting is applied, nor is the design life of the turbine used.	No specific guidance		
	10.8 Damage equivalent load		- Is the formula reported?		
	10.9 Wind speed binning		No specific guidance		

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
	10.10 Power spectral density	PSD calculations shall be performed on the load quantities in Table 9 for the dynamic measurement load cases. The following information on the analysis shall be reported: • Reference to the PSD algorithm used • Frequency resolution • Number of lines in the spectrum • Windowing type • Length of applied window • Averaging and/or overlapping	No specific guidance		
	Reporting Clause 12.9)	7) Post processing methods, such as: a) Filtering during post processing; b) Despiking; c) Description of calculated channels (tower fore-aft from tower bending and yaw position etc.); d) Rainflow cycle counting method; e) Wind speed trend detection method f) Any additional data treatment	- Check that all the used post processing methods have been included in the report - Do those methods lead a solid result?		

6.8 Uncertainty estimation

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
	11 Uncertainty estimation Annex B	The uncertainties for all reported quantities shall be evaluated and reported. The uncertainty evaluation shall consider all relevant sources of uncertainty which occur in the measurement results.	- Are the uncertainties derived as per Annex B		
	Reporting Clause 12.9)	11) Uncertainty per the requirements of Clause 11 a) For measured quantities: i) A table of values of the uncertainty sources that were used in the estimation of the total standard uncertainty of the quantity (for example see Table B.1 in Annex B) ii) A statement of the total standard uncertainty of the measured quantity (percentage and constant) b) For binned results: i) A table with the total standard uncertainty for the bin-averaged value of the measured quantity as a function of bin-average wind speed ii) A table with the total standard uncertainty for the bin-averaged value of the DEL of the measured quantity as a function of bin averaged wind speed c) For damage equivalent loads and cumulative rainflow spectra: i) The statement of the total standard uncertainty of the ten minute DEL for the measured quantity (percentage only) ii) Uncertainty of the cumulative rainflow spectrum (percentage on the ranges)	- Check that all points have been included in the report		

6.9 Minimum test report results

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
	Reporting Clause 10) Results.	At a minimum the following results shall be included in the test report (except where marked as optional):	- Check that all points have been included in the report - Is the report according to the IECRE minimum report requirements' template		
		a) For the test period: i) Plots of meteorological conditions as a function of time (ten minute means), including: Wind speed, Wind direction, TI, Air density, Wind shear			
		ii) TI as a function of wind speed			
		iii) TI de-trended and as-measured as function of wind speed (ratio, difference or both;			
		iv) Scatter plot of meteorological conditions as a function of wind direction (ten minute averages), including: Wind speed, TI, Shear			
		iv) Frequency spectra indicating the frequencies values of found peaks in the spectrum with indication of rpm or 1P.			
		v) Cumulative rainflow spectrum for fundamental loads in Table 9			
		vi) Table with mean of means, maximum of ten minute maxima, minimum of ten minute minima and bin averaged damage equivalent loads for wind speed in 1 m/s bins for all meteorological signals (mandatory signals in Table 11, all turbine operational quantities) mandatory signals in Table 12 and all fundamental loads quantities (Table 9) (optional).			
		vii) Plots of binned Ct and Cp as a function of wind speed (optional)			
		viii) Items above for any other mandatory signals in Table 10			
		c) For transient events: i) Capture matrices, including reference to the file identifier containing the events			
		ii) For one of each type of event: time series of mandatory meteorological, turbine operational quantities and fundamental load quantities identified in Tables 9, 11 and 12			
		iii) Table with statistics of each channel during the transient (recommended)			
		d) Parked conditions: i) Capture matrix linking to filenames			
		ii) Time series (600 s instead of 60 s) one example for each target yaw misalignment.			
		e) Dynamic measurement load cases: i) Spectra for each DLC for the targeted load quantities			
		f) For turbines with a rated power output greater than 1 500 kW and rotor diameter greater than 75 m the reporting requirements for the additional mandatory load quantities are the same as for those identified above for the signals in Table 9.			

7 Document improvement

#	Reference to section in standard	Requirement from standard	Checks & expert guidance	Reported / Inspected	Finding
	No reference	No reference	- Note suggestions for improvements of this document		

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