MEASNET LOADS – Commenting ‘IEC-Dash-13‘

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Summary
Under the roof of MEASNET a group of experts from the leading load measurement service suppliers has formed to create a MEASNET procedure for load measurements on wind turbines. The process which was started three years ago targets to enhance quality load measurement services beyond the scope of the IEC TS 61400-13 guideline. State of the art load measurement practice follows the IEC TS 61400-13, First edition, 2001/06, Wind turbine generator systems - Part 13: Measurement of mechanical loads. The "Dash-13" is effective since June 2001 and now, after 5 years of practical application the MEASNET expert group has set out to compile the experiences made in several thousand hours of measurements. At the same time an IEC initiative for a revision of the "Dash-13" is anticipated. Highlighting the difficulties and shortcomings when applying the guideline and proposals on how these can be overcome is focus of this paper. However, discussion in the MEASNET Loads Expert Group is still continuing.

1. Introduction

1.1 The MEASNET Loads Expert Group

MEASNET is a network of measurement institutes, which has been established to harmonize wind energy related measurement procedures. All members of MEASNET are actively performing wind energy related measurements and have documented their skills and quality in performance of measurements by having established their individual accreditation in the corresponding national accreditation system. Members of MEASNET are bound to apply agreed 'MEASNET measurement procedures' and to maintain their high standard of service through participation in mandatory mutual evaluation exercises - so called round robin tests.

1.2 Difficulties and Shortcomings of "Dash-13"

In the following the difficulties and shortcomings that the authors have come across when applying the guideline are highlighted:

- To which degree the requirements of the users of load measurement services are mirrored in the guideline.
- How to deal with insufficiency of wind speed range and turbulence levels covered during the measurements due to characteristics of the test site.
- Importance of external parameters on the loading results s.a. vertical wind gradient, atmospheric boundary layer conditions.

- Concept of de-trending of wind speed for categorizing load measurement time series and for comparison with simulated loads.
- Concept of load spectra generation from the load data base.
- Calibration of load quantities.
- Analysis and rating of relevant error sources in load measurements.

The mentioned topics are under discussion in the MEASNET Loads Expert Group.

2. The User's Requirements

2.1 The (End) User

Two (end) user groups for *results* from load measurements according to "Dash-13"-guideline are identified:

- The design engineer at the wind turbine (component) manufacturer
  The designer's interest is to make sure the design tools used in the design process are delivering sufficiently accurate information. This degree of sufficiency is established by comparison of a number of criteria that are applied on both, simulated and measured load data.
- The certifying body / consultant
  The certification engineer's task is to assess or even prepare the engineer's statement on the degree to which the design loads used for the dimensioning of the turbine components maintain a desired amount of conservatism. Based on this judgment a certificate is issued.

The difference between both groups is that the design engineers seek deeper insight into the loading mechanisms and how these can be modeled best. The certification engineer has more of a comprehensive task trying to make sure state of the art design & modeling techniques and production techniques are applied. Obviously they both have a different point of view. Bearing this in mind and looking at the provisions in the "Dash-13"-guideline the question may be raised whether or not the specifications given there are adequate.

2.2 The User (e.g. the Measurement Institute)

The main users of the "Dash-13"-guideline are the measurement service suppliers. They are the ones to deliver a report about the results of a load measurement campaign to the end user - it is the responsibility of the institute to explain how and under which conditions these results were obtained. Realizing delivery of comparable results from a load measurement according to the "Dash-13"-guideline leads to the necessity of harmonizing the following:

2.2.1 Uncertainties Due to Drift Effects

Drift effects might be observed during a load measurement campaign, that is typically running over a period of several months.

Generally speaking drift effects are caused amongst others by non-linear material behavior, temperature effects and strain gauge amplifier drift.

Even if an observed drift was corrected it cannot be assumed, that the correction was fully successful in all operating data. Therefore, an uncertainty level must be defined to be taken into consideration for the uncertainty estimation in the time series as well as the mean load versus wind speed presentation. IEC Dash-13 (chapter B.2.2 and B.2.3) leaves this uncertainty to be estimated by the experimenter.

According to DIN VDI/VDE 2600 such errors may be treated analogue to stochastic errors given that the corrected maximum drift (=undetectable systematic error) is smaller than 1/10th of the combined stochastic error of the signal. In this case the maximum drift error may be combined geometrically with the stochastic error. In the other case the error must be arithmetically added to the stochastic uncertainty.

The undetectable systematic error may be estimated by observation of the output value under constant external / loading conditions - a difficult, sometimes impossible task.

2.2.2 Treatment of Wind Speed Trend Data

As described in IEC chapter 5.4.1 "Caution should be taken that slow variation in wind speed may result in non-representative high turbulence intensity estimates, for example steady increase or stepwise changes in wind speed during the 10 min. A representative set of measurements can be achieved either by selecting only 10-min samples with a steady mean wind speed or by high-pass filtering the wind speed before calculating the turbulence intensity."

The option of selecting only wind speed time series with a steady mean wind speed is the most restrictive approach, but may not be applicable at sites where high wind speeds coincide with such trendy behavior. As in such cases the data sets shall still be usable it is required to derive a realistic turbulence intensity and grade the data set correspondingly. Applying filters on the wind speed data proved to have some problems hence another scheme is suggested:

- compute the mean value for each consecutive 1-minute period within a 10-minute-data set
- subtract this mean value from the corresponding wind speed signal ?
- compute the standard deviation for the derived wind speed signal (now varying around zero)
- compute turbulence intensity using de-trended standard deviation and original 10-minute mean value

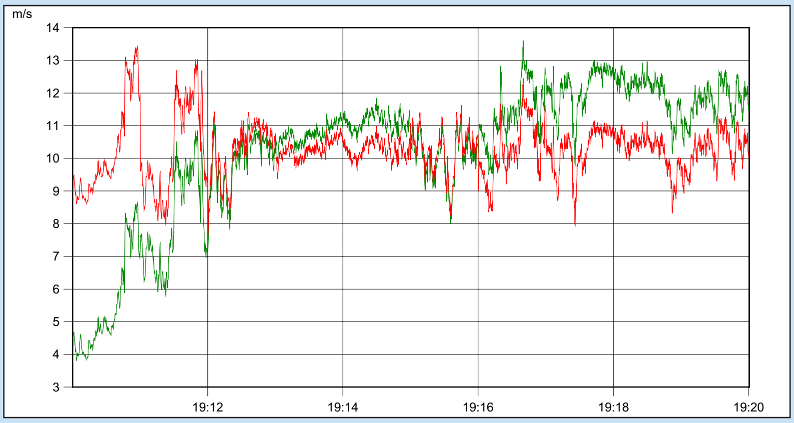
The data sets must subsequently be re-binned for the new de-trended turbulence intensity.

Comparison to simulated wind speeds show that this approach delivers structurally comparable turbulence. The advantage of this approach is that the data are just sorted into another turbulence BIN. It is to be noted that the de-trending process is not applied to the load data itself. This may lead to some extra conservatism as compared to simulated load time series.

In a load measurement campaign with a sufficient amount of "steady" data a trend-level threshold definition can be used. Data sets exceeding the trend-level threshold are discarded from the database. The data sets above the trend-level threshold may be used for special analysis. Therefore, they shall be stated and highlighted in the capture matrix (for instance in brackets).

Fig. 1: De-trending

v_hub_2_cc (green) = original wind speed
v_hub_2_cc_t (red) = de-trended wind speed



The trend-level is calculated according equation 1.

Data sets with a Trend-level threshold >$4.5*10^{-3}s^{-1}$ shall be treated as trend data. The threshold of $4.5*10^{-3}s^{-1}$ has been determined by experimental analysis of time series and simulation tools, but may be re-defined and stated by the experimenter.

$$T = \frac{|slope|}{std(WS)}$$

T	Trend-level
$\|slope\|$	wind speed regression line slope
$std(WS)$	standard deviation of wind speed

Equation 1

2.2.3 Extrapolation to other Turbulence Levels

The "Dash-13" gives two approaches to extrapolate a given fatigue load (range) spectrum to a turbulence level beyond the level measured:

- Linear Extrapolation
- Spectrum Distribution Modeling

In everyday experience the need for such extrapolation seems limited. As a matter of fact in most cases the customer does not ask for such extrapolation. The more realistic path in design load validation is to prove the computational turbine model (simulation) to deliver realistic loads at one or two turbulence levels. Having done so, it seems to be acceptable to determine the design loads for even higher (than measured) turbulence levels through simulations only. This approach assumes that the computational model works sufficiently for different turbulence levels without having to change crucial parameters like system natural frequencies, structural and aerodynamic damping and maybe others.

2.2.4 Wind Speed

The (free-in-flow) wind speed is an important input value for the results of a load measurement campaign. The "Dash-13" *recommends* to measure the wind speed according to the IEC guideline for power performance measurement (IEC 61400-12).

Due to the complexity of the wind field across the rotor swept area the standard procedure for wind speed measurement (with a single anemometer at hub height) may lead to an insufficient description of the inflow to the rotor.

Effects to be considered are:

- site calibration correction
- wind profile
- nacelle based wind speed measurement

2.2.5 "non-closed" BINs in a Capture Matrix

To determine the load spectrum of a wind turbine component from measured time series, the requirements for capture matrices in clause 3 of the "Dash-13" should be fulfilled. However, at the end of a measurement campaign it might occur that some of the wind speed BINs in the capture matrix for normal power production are still empty. To enable the comparison with numerical simulations an approach is proposed where one should distinguish between empty wind speed BINs above the highest measured wind speed and intermediary empty wind speed BINs.

It is advised not to take into consideration the empty wind speed BINs above the highest measured wind speed. For mutual comparison this cut off at the highest measured wind speed should be applied in the simulations also.

For the intermediary empty wind speed BINs it is advised to apply the same number of datasets from the corresponding higher and lower wind speed BINs.

2.2.6 Calibration of Strain Gauge Signals

Due to increasing turbine size, the introduction of external loads is difficult and expensive.

For homogeneous materials with known material parameters and known geometry (e.g. tubular steel tower and main gearbox shaft), the option of shunt calibration is mentioned in chapter 4.2.1.3.1 of the IEC TS 61400-13.

With rotor blades, the replacement of the variable external load by the known dead weight of the blade for calibration purposes is described in chapter 4.2.2.2.

The guideline does not provide a detailed description of the proceeding as well as of the uncertainty consideration regarding both aforementioned procedures. Both calibration procedures are presented in the following.

2.2.6.1 Analytical Shunt Calibration

The procedure and the requirements are mentioned in chapter 4.2.1.3.1. The calibration coefficient A1 of the signal is determined as regression via a variation of the shunt resistor that covers the entire measuring range. The evaluation of the category A Error is done via the standard deviation of the individual rises A_{1n}.

The combined uncertainty of category B derives when considering the uncertainties of the following components:

- Signal (measurement chain)
- Young's-modulus
- Gauge-factor
- Poisson's-ratio
- Geometry
- Shunt resistance
- Gauge resistance
- Bonding
- Orientation
- Crosstalk
- Strain concentration

The following consideration of uncertainties is carried out analogous to Annex B of the IEC TS 61400-13.

2.2.6.2 Dead Weight Calibration (e.g. Rotor Blades)

In chapter 2.1.1 of the IEC TS 61400-13, the blade calibration procedure by determining a two-dimensional matrix is described. The procedure is based on an independent initiation of known variable calibration moments, in edge- resp. flap-direction. Possibly occurring crosstalk of signals are considered in this matrix. In case of pitch and active stall regulated turbines, this can be determined by idling tests, independently for edge and flap with pitch angles as close as possible to 0° and 90°. In case of stall-regulated turbines, this is only possible for the edge-signal. The calibration of the flap-signal has to be carried out via external load.

To determine A1…A4, both signals into edge- and flap direction are recorded as well as the rotor angle during an idling test. During the test, the pitch angle has to maintain constant. The tests have to be carried out at low wind speed; the rotor speed should be low as well. It is recommended to record several rotations.

The calibration moments are calculated at the cross section where the strain gauges are mounted on basis of the mass distribution of the blade and, if applicable, under consideration of tilt- and cone-angle as a function of the rotor angle for both direction components (edge, flap). The coefficients A1 and A4 resp. A2 and A3 are determined as regression of the measured signal each via the calculated calibration moment.

The category A Error derived from the regression is occurring with this procedure, too.

The combined uncertainty of category B derives if the uncertainties of the following components are considered analogous to Annex B of the IEC TS 61400-13.

- Pitch angle
- Rotor angle
- Cone angle
- Tilt angle
- Mass distribution of the rotor blade
- Position of the strain gauges

2.2.7 MLC's and LTF in Load Spectra

In the fatigue analysis the wind turbine duty cycle is described through the wind speed distribution and a specific number of transient events. In this philosophy each wind speed BIN is considered as an individual Measurement Load Case (MLC) that is to be weighted according to its frequency of occurrence throughout the turbine's service life. This frequency is given by a specific wind speed distribution which is normally chosen to be identical with the one that has been used in the design of the turbine e.g. a Rayleigh distribution with average wind speed of 8.5m/s as assumed for wind turbines class II in the International Standard IEC 61400-1. The fatigue load spectra are then found by superposition and extrapolation of the rainflow counted load cycles that can be found within each of the time series used to describe a given MLC. In this procedure the loading effect of the wind speed varying from one 10-minute average to another respectively from one measurement load case to another is neglected. The loading arising from these transitions between the load cases (MLCs) is referred to as Low Transitional Fatigue (LTF).

2.2.8 Rainflow Counting Method

Rainflow counting shall be carried out according to IEC standard requirements, clause 5.4.2.

In reports and regarding the fatigue load spectra for each measured time history, detailed documentation of the applied rainflow counting methodology is to be given in order to enable more accurate comparisons with numerical simulations. As a minimum, reports shall contain the following issues:

- Number of BINs.
- Usage of fix or variable BIN width.
- Assumptions regarding to lower and upper boundaries of the BINs.
- If a fix BIN width is applied:
  - Full scale minimum.
  - Full scale maximum.
- Hysteresis as a percentage of BIN width.
- Treatment of residuals. It is advised to include a short description of the applied procedure.

For the load spectra corresponding to lifetime operation, additional information shall be reported:

- The procedure used to combine the rainflow counts of the individual 10-min-time series. Questions like how the residual is added to the final matrix should be clarified.
- List of the events included.
- Service life.
- Wind speed distribution.
- The probability is to be considered for the wind speed BIN middle.
- RFC software version.