Advances in the Treatment of the Influence of Meteorological Variables on Wind Turbine Power Curves in Warranties

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Summary

The influence of meteorological conditions on wind turbine power curves must be considered for warranties as on the one hand wind turbine suppliers can guarantee power curves only for certain reference conditions and as on the other hand wind farm owners desire a warranted power curve matching the conditions of their wind farm site. The classical method of additional data filtering often makes power curve verifications impracticable due to lacking data. The filtered power curve may also be less representative for the wind farm site. Data normalisation to the reference conditions of the warranted power curve according to CDV IEC 6140-12-1, Ed.2 is a good alternative to data filtering, but the normalisation methods don't cover all effects. Covering the impact of meteorological conditions by additional uncertainties of power curve tests according to CDV IEC 6140-12-1, Ed.2 is another alternative, but these uncertainties can significantly reduce the effective warranty level. Most issues can be solved by warranting site specific power curves. This method may be combined with data filtering, data normalisation or additional uncertainties in order to take care for possible seasonal effects on power curve tests. The so-called inner/outer range concept simplifies power curve verifications, but the determination of the inner and outer range and the additional uncertainty to be considered in the outer range is problematic. Finally, warranting power curves in form of a black-box simulation tool, which calculates a warranted power value for the input conditions measured in each 10-minute period, may be a promising future method.

1 Introduction

Wind turbine power curves are influenced by meteorological conditions, e.g. by the turbulence intensity and the wind shear. This must be considered for power curve warranties. Wind turbine suppliers (OEMs) cannot overtake the risk that a warranted power curve is not met due to site specific meteorological conditions significantly different from the reference conditions of the warranted power curve. The current power curve testing standards [1], [2] hardly address this issue, i.e. the wind turbine power output is evaluated as function of the wind speed at hub height and the air density only in these standards. Therefore, OEMs often include additional requirements to the testing standards for verifying the warranted power curve in power curve warranties. On the other hand, for wind farm developers and operators the real world power curve examined at their wind farm site is the relevant measure for economic considerations and should ideally be warranted. Advanced procedures how to deal with this conflict have been developed over the past years in the frame of designing and negotiating power curve warranties, within the revision of the standard IEC 61400-12-1 [3] and within the Power Curve Working Group [4]. 6 different methods are discussed and compared in the following chapters.

2 Method 1: Additional Filtering of Power Curve Testing Data

One method to make a measured power curve better comparable to a warranted power curve is to filter the power curve data to influencing variables in ranges around the reference conditions of the warranted power curve. It is noted that such data filtering represents a special database according to the power curve testing standard IEC 61400-12-1 [1], [3] and not the main result of a power curve test according to the standard. Nevertheless, filtering out turbulence intensities outside the range 6 % to 12 % from power curve tests is for instance required by the German Technical Guideline 2 [5] since many years in order to make measured power curve of different types of turbines better comparable in the frame of the regulations of the German Renewable Energy Sources Act [6].

Additional data filtering is today required in most standard warranties offered by OEMs, while the filter variables and filter ranges are specified very differently across the warranties. Most OEMs

require filtering according to the turbulence intensity. The accepted turbulence ranges are sometimes as small as from 8 % to 12 % turbulence intensity over the entire wind speed range, and sometimes much wider and dependent on the wind speed. Some turbine suppliers require filtering out power curve testing data with very low turbulence intensities with the argument that low turbulence intensities are often coupled with non-standard wind shear (vertical wind speed gradient) and wind veer (vertical wind direction gradient) conditions, which lead to worse power curves. Indeed higher than expected power curve issues at low turbulence intensity combined with low wind speeds are also reported in [7] (also known as 4th quadrant problem).

Overall, additional filtering of power curve testing data has the following advantages over the other methods:

- No assumptions on models for describing the influence of meteorological variables on the power curve are needed. Undesired testing conditions are rather filtered out directly.
- No additional uncertainty of the measured power curve due to the impact of the filtered meteorological variables is introduced. The uncertainty of power curve tests is mostly interpreted to the advantage of the OEM in power curve warranties, as the warranty provider cannot be hold responsible for the measurement uncertainties. Hence, avoiding additional uncertainties effectively increases the power curve warranty level.
- Higher cost of a wind speed measurement covering the entire height range of the WT rotor to determine the so-called rotor equivalent wind speed (REWS) for taking care of shear and veer effects according to [3] may be avoided. Undesired shear and veer conditions may rather be filtered out indirectly by a turbulence filter as a proxy.

Disadvantages of additional filtering of power curve testing data compared to the other methods are:

- Often a significant amount of the available data is filtered out (typically 30 % to 80 % of all data). In the best case, this leads only to the extension of the measurement period. In the worst case, a power curve test becomes impossible due to additional data filtering.
- The size of the filter window must be selected as a compromise. If a large filter range is chosen, more data remains for the power curve evaluation. However, significant influences of meteorological variables may remain with large filter ranges. If a small filter range is chosen, a lack of data for the power curve evaluation is likely.
- The warranted and verified power curve may not be representative for the mean meteorological conditions of the considered wind farm site if the filter ranges deviate much from the typical site conditions. As a consequence, the warranted and verified power curve may lead to errors in wind resource assessments and economic projections. Often, the warranted power curve is valid for idealised conditions rather than realistic conditions such that their application for wind resource assessments leads in tendency to overestimations of the achievable energy yield.
- A gap in most power curve warranties is the treatment of additional data filtering in the context of site calibrations. There are two aspects: The one being whether to apply the data filtering required for the power curve analysis also for the evaluation of the site calibration, the other in how far meteorological conditions as measured with the reference wind measurement in a distance of 2 to 4 rotor diameters from the test turbine are representative for the turbine position in non-simple terrain.
  In terms of data filtering of site calibration data, the current standard IEC 61400-12-1, Ed.1 [1] specifies that filtering of special atmospheric conditions used for the power curve test shall also be implemented for the evaluation of the site calibration. On the other hand, IEC 61400-12-1, Ed.1 defines power curves evaluated with such filters only as special database and not as main result of the power curve test. In practice, any additional filtering of site calibration data often leads to a lack of available data. Therefore, it was decided for the German Technical Guideline 2 [5] that the turbulence filter, as it is desired in this guideline for power curve tests, shall not be applied for site calibrations. In any case, it should clearly be specified in warranties when a special filter on meteorological conditions shall be applied or not in order to avoid arbitration. A meaningful guidance is that such data filtering shall be performed only if the result of the site calibration is found being significantly influenced by such filtering. It must be understood in this context that site calibration results can be dependent on completely different variables than wind turbine power curves. For instance, the turbulence intensity will likely have a signif-

icant influence on power curves, while it must not have a significant influence on the site calibration.

In complex terrain, power curve influencing variables like the turbulence intensity or the wind shear may vary significantly over distances of a few hundred meters, i.e. over the distance of the reference wind measurement to the test turbine (for the case the test turbine would not be present). If in such cases a meteorological variable as measured at the reference measurement position is directly applied to filter power cure data, an undesired range of that variable may be present in the power curve analysis. This should then be overcome by evaluating and applying a site calibration of the filter variable. Such a site calibration is conditioned on a sufficient correlation of the filter variable at the reference measurement position and the future turbine position during the site calibration. It has been observed that sometimes the correlation of some filter variables across the two measurement positions is too poor for evaluating a site calibration on such variables, even if the correlation of wind speed data is high. In such cases, no filtering of the power curve data according to the respective meteorological variables is possible. According to the author's knowledge, only one OEM has included a detailed description how to treat site calibrations on meteorological variables other than wind speed in his standard power curve warranty. All other warranties have a gap in this respect, which can lead to arbitrary power curve testing results.

3 Method 2: Data Normalisation

CDV IEC 61400-12-1, Ed.2 [3] includes the following procedures of normalising power curve data to reference conditions for taking care of the influence of the respective meteorological variables on the measured power curve:

- Normative air density normalisation to the reference air density similar to the current standard IEC 61400-12-1, Ed.1 [1]
- Optional application of the so-called rotor equivalent wind speed (REWS). The REWS describes the kinetic energy available over the height range of the wind turbine rotor. It can be determined by only taking into account the wind shear measured over the height range of the rotor or in addition by accounting for the wind veer relative to the wind direction at hub height. A power curve evaluated as function of the rotor equivalent wind speed is assumed to be less sensitive to wind shear effects (and wind veer effects if also the wind direction is taken into account) compared to a power curve evaluated as function of the wind speed at hub height only.
- As alternative to the REWS based power curve: normalisation to reference wind shear or wind veer conditions. The mathematics of this normalisation are equivalent to the REWS approach, but the resulting power curve still refers the wind speed at hub height, while the so determined power curve is valid for the pre-defined reference wind shear or veer conditions [3], [8]. The reference wind shear or wind veer can be selected being dependent on the wind speed. The REWS based power curve can also be considered as a special case of such a normalisation of the measured power curve to a wind shear of 0 and wind veer of 0° (flat wind shear and no wind veer).
- Optional normalisation of the power curve to a reference turbulence intensity. The reference turbulence intensity can be selected being dependent on the wind speed [3], [8].

It is noted that the normalisation procedures given in [3] are approximations of the real effect of the variables air density, wind shear, wind veer and turbulence intensity on the measured power curve. Uncertainties of the normalisation procedures must be considered according to [3]. Furthermore, if one of the optional normalisations is not carried out, the full possible effect of that variable on the measured power curve must be applied as additional uncertainty according to [3].

It is further noted that CDV IEC 61400-12-1, Ed.2 [3] does not include a procedure to correct power curve data according to the vertical flow inclination, while an uncertainty of the power curve due to not taking care of the effect of vertical flow inclination is integrated in [3]. An extension of the REWS under inclusion of the impact of the flow inclination on measured power curves is given in [9], where only the wind speed component along the rotor axis is integrated over the height range of the rotor for the calculation of the REWS:

$$V_{eq} = \left(\frac{1}{A} \sum_{i=1}^{n_h} \left(V_i \cos(\phi_i - \phi_h) \frac{\cos(\theta_i + \theta_{tilt})}{\cos(\theta_i)} \right)^3 A_i \right)^{\frac{1}{3}}$$

where

V_{eq}:   rotor equivalent wind speed under inclusion of flow inclination angle
A: rotor swept area
A_i: area of rotor segment centred at i-th measurement height
n_h: number of measurement heights
V_i: horizontal wind speed component measured at i-th height
ϕ_i: wind direction measured at i-th height
ϕ_h: wind direction measured at hub height
θ_i: flow inclination measured at i-th height
θ_{tilt}:   rotor tilt angle

Annex P of CDV IEC 61400-12-1, Ed.2 [3] can be extended with this modified REWS to a nor-malisation of the hub height wind speed to a reference profile of the vertical flow inclination by extending the reference wind shear correction factor $f_{r,reference}$ to:

$$f_{r,reference} = \left(\frac{1}{A} \sum_{i=1}^{m_h} \left(\frac{\tilde{V}_i}{\tilde{V}_h} \cos(\tilde{\phi}_i - \tilde{\phi}_h) \frac{\cos(\tilde{\theta}_i + \theta_{tilt})}{\cos(\tilde{\theta}_i)} \right)^3 \tilde{A}_i \right)^{\frac{1}{3}}$$

where
m_h: number of heights within rotor height range used for the definition of a reference wind profile

$\tilde{A}_i$:   area of rotor segment centred at i-th height as used to define the reference wind profile

$\dfrac{\tilde{V}_i}{\tilde{V}_h}$:   ratio of horizontal wind speed component at i-th height and at hub height used to define the reference wind shear. This ratio may be selected as function of the wind speed.

$\tilde{\phi}_i - \tilde{\phi}_h$:   difference of wind direction at i-th height and at hub height used to define the refer-ence wind veer. This difference may be selected as function of the wind speed.

$\tilde{\theta}_i$:   reference flow inclination at i-th height as used to define the reference wind profile (may be selected as function of the wind speed)

The hub height wind speed normalised to the reference wind shear, the reference wind veer and the reference flow inclination profile is then gained as ratio of the REWS and $f_{r,reference}$ according to the above two equations.
The power curve normalisations given in CDV IEC 61400-12-1, Ed.2 [3] and the extension to the normalisation according to a reference profile of the vertical flow inclination can be utilised in power warranties and wind resource assessments as follows:
- The power curve testing data can be normalised to the reference air density, wind shear, wind veer, turbulence intensity and flow inclination of the warranted power curve in order to improve the comparability of the two power curves. It is noted that all reference condi-tions of the warranted power curve can be selected being wind speed dependent.
- If the warranted power curve refers to the REWS wind speed definition, the REWS wind speed definition should also be applied for wind resource assessments in order to en-sure compliance of the evaluated wind resource with the warranted power curve. If the warranted power curve refers to the hub height wind speed definition in combination with reference profiles for the different meteorological variables (air density, wind shear, veer, turbulence intensity, flow inclination), the warranted power curve should be normal-ised to the expected site conditions for wind resource assessments, as it is common

practice since a long time in terms of the air density. Both approaches, REWS and normalisation to wind shear, veer and flow inclination, as well as the turbulence normalisation and the air density normalisation can also be implemented to time series data of the wind conditions for wind resource assessments. However, care should then be taken to avoid effects from interpolating the binned power curve for evaluating a time series of the power production [10], [11].

Power curve normalisation according to CDV IEC 61400-12-1, Ed.2 [3] has the following advantages over other methods to take care for the impact of meteorological variables on power curves in warranties:

- A full description in terms of the treatment of air density, wind shear, wind veer and turbulence intensity is given in [3]. The publication of the final standard is expected in early 2017.
- The method can be extended to the treatment of vertical flow inclination as described in [9] and above.
- No data is lost by filtering, as filtering of power curve data according to the meteorological variables influential on the power curve is avoided.
- Imperfections of the normalisation procedures are covered by the associated uncertainties introduced in [3]. These additional uncertainties would be accounted to the advantage of the warranty provider.
- The normalisation procedures can be used to convert the warranted power curve to the site specific conditions for wind resource assessments in order to ensure compliance of the power curve warranty with economic considerations. For this purpose, the imperfections of the normalisation procedures should be taken into account in the uncertainty budget of the wind resource assessment.

Disadvantages of the normalisation procedures in terms of power curve warranties compared to other methods are:

- The REWS approach is linked to high cost of the wind measurements as the entire height range of the rotor has to be covered. In complex terrain, following the REWS approach requires the use of upper tip height met masts for the site calibration and power curve test, what is hardly affordable in case of modern large wind turbines. In simple terrain, the combination of a wind speed measurement with a LiDAR and a short control met mast according to [3] seems to be an attractive measurement set-up to keep down the cost of power curve tests and still allowing the implementation of the REWS approach. It is pointed out in this context that also stand-alone applications of LiDAR may be feasible with substitutes for the control mast by appropriate measure to keep under control the consistency of the LiDAR measurements.
- The normalisation procedures have imperfections, which increase with increasing differences of the measured meteorological conditions and the reference conditions of the warranted power curve. The turbulence normalisation given in [3], although being effective, describes only part of the true turbulence effects on the power curve. The REWS approach has shortcomings especially in case of very high wind shear, as then the kinetic energy available in the rotor height range cannot be fully utilised by today's wind turbines. The uncertainties associated to these imperfections can be significant. It is noted in this respect, that CDV IEC 61400-12-1, Ed.2 [3] does not take into account uncertainties of imperfections of the REWS approach if the REWS definition power curve is evaluated (gap in the standard). An appropriate uncertainty is only considered if the power curve is evaluated for the hub height wind speed in combination with data normalisation to a reference wind shear or veer.
- In complex terrain, the meteorological variables other than wind speed at the position of the reference wind measurement may deviate from the conditions at the turbine position. A site calibration of the respective variables is then needed in order to be able to apply the normalisation procedure. The description of the site calibration in terms of the influential variables (other than wind speed) given in CDV IEC 61400-12-1, Ed.2 [3] is poor. Furthermore, it is often observed that the correlation of wind shear, wind veer and turbulence intensity at the position of the position of the reference wind measurement

and the position of the test turbine is much weaker than the correlation of the wind speed. Sometimes, a site calibration on these variables is impossible.

4 Method 3: Additional Uncertainties

Another approach to deal with the impact of meteorological variables other than wind speed and air density on the power curve is to treat all the possible impacts as additional uncertainties which are accounted to the advantage of the warranty provider. The power curve verification is then done by a simple measurement of the hub height wind speed without any additional data filtering and without any data normalisation except of the common air density correction.
Advantages of this method are:
- CDV IEC 61400-12-1, Ed.2 [3] provides guidance how these uncertainties can be assessed.
- Data loss by additional filtering is avoided.
- Higher cost of measurements of the REWS is avoided.
- No special treatment of the influential variables in case of site calibrations is needed.
- Consistency of the power curve warranty and wind resource assessments can be achieved by applying the same uncertainty model also for wind resource assessments.

Disadvantages of the approach are:
- The additional uncertainties can be significant. This can result in a high reduction of the effective power curve warranty level.
- The warranted and verified power curve may not be representative for the mean meteorological conditions of the considered wind farm site. This can lead to a significant bias in economic considerations for the wind farm project.

5 Method 4: Warranty of a Site Specific Power Curve

A further approach is to warrant a power curve which is adjusted to the mean site specific conditions in terms of the influential variables. The power curve verification is in this case done by a simple measurement of the hub height wind speed without any additional data filtering and without any data normalisation except of an air density correction. Uncertainties of the air density correction are reduced by the fact that the power curve is warranted for the mean site specific air density.

Advantages of Warranties of Site Specific Power Curves are:
- The warranted power curve is representative for the site conditions. Application of this power curve for wind resource assessments should lead to realistic expectations.
- Data loss by additional filtering is avoided.
- Uncertainties of the power curve verification due to the impact of meteorological variables other than wind speed are reduced. As the uncertainty of the power curve verification is usually taken to the advantage of the OEM, the effective warranty level is improved.
- Higher cost of measurements of the REWS is avoided for the power curve verification.
- No special treatment of the influential variables in case of site calibrations is needed.

Disadvantages of Warranties of Site Specific Power Curves are:
- It is not simple to determine all information needed to calculate a site specific power curve. OEM's sometimes have problems to get appropriate information from wind farm developers.
- Some uncertainty of the power curve verification due to the impact of meteorological variables other than wind speed remains, because the respective conditions in the testing period can deviate from the mean conditions at the site (seasonal effects).
- More expensive measurements of the REWS are desirable in the planning phase of the wind farm to provide proper input for determining the site specific power curve. This would be a shift of cost for the REWS measurement from the power curve verification to the wind resource measurements. It is pointed out that even if exemplary REWS meas-

urements are available in the planning phase, the accuracy of the determination of the REWS at each planned wind turbine position suffers from uncertainties of the flow models (uneven uncertainties in different heights above ground).

6 Method 5: Inner / Outer Range Concept

The so-called Inner / Outer Range procedure [12] has been broad up in the frame of the work of the Power Curve Working Group [4]. This approach is based on the observation that additional data filtering, as it is often required for the verification of warranted power curves, usually has only little impact on the evaluated power curve, while such filtering can be a significant hurdle in carrying out power curve verifications (see chapter 2). Consequently, the Inner / Outer Range does not include any additional data filtering. In order to take care for the impact of meteorological variables other than wind speed, these variables are separated into two ranges. In the "inner" range, a power curve is warranted to 100 % in terms of the annual energy production (AEP), while in the remaining "outer" range the warranty level of the same power curve is below 100 %. An effective warranty level is then evaluated by weighting the warranty level of the inner range and the warranty level of the outer range by the fraction of the frequency of occurrence of the inner range and outer range in within the power curve testing period. The measured power curve is finally compared in terms of its AEP with this effective warranty level in order to validate the warranty.

Advantages of the Inner / Outer Range concept are:
- Data loss by additional filtering is avoided for the power curve verification.
- Higher cost of measurements of the REWS is avoided.
- The method is simple to implement in warranties and to apply for verifying warranted power curves.
- The concept can be implemented in wind resource assessments in order to reach consistency with the power curve warranty. For the fraction of time of a long-year period with the meteorological conditions expected being in the outer range, the AEP calculated with the warranted power curve just needs to be reduced according to the reduced warranty level of the outer range.

Disadvantages of the Inner / Outer Range concept are:
- The warranted power curve may not be representative for the site conditions. Application of the warranted power curve for economic considerations can lead to errors despite a consistent treatment of the concept in the power curve warranty and wind resource assessment.
- The determination of a proper boarder between the inner range and outer range is difficult for OEMs. In general, a calculated power curve is valid only for specific values of the influential variables, not for ranges of these variables, i.e. the real power curve is influenced by meteorological variables other than wind speed also in the inner range. Furthermore, wind farm owners wish the inner range to cover most of the site specific conditions in order to reach a high effective warranty level, i.e. a site specific selection of the inner range, the outer range and the warranted power curve is desirable.
- The reduction of the warranty level in the outer range is difficult to determine for OEMs. The expected influence of the meteorological variables other than wind speed in the outer range on the power curve test needs to be assessed for that purpose. This requires knowledge of the expected outer range, i.e. detailed knowledge of the site specific conditions. More expensive REWS measurements are desirable for the site assessment to accurately determine the site specific conditions.

7 Method 6: Warranted Power Curve in Form of a Simulation Model

Instead of warranting a certain power curve as function of electrical power output versus wind speed, OEMs may warrant the electrical power output in form of a black box computer code, which provides the electrical power output for a set of input variables, while both, the output and input variables, refer to data averaging in time over 10 minutes. For verifying the warranty, a power curve of a test turbine is measured without additional data filtering according to meteoro-

logical variables and without application of any data normalisation procedures. The warranted power is then calculated for each 10-minute period of the power curve testing period with the warranted simulation model for the set of measured input variables and is also bin averaged against the wind speed. Finally, the so generated warranted power curve is compared to the measured power curve.

As an alternative to providing the warranted power curve as a black box simulation model, the electrical power output may also be warranted in form of a (digital) multidimensional matrix of set of input variables. The warranted power output for a set of measured input variables within a 10-minute period is then determined by interpolating between the matrix elements.

Advantages of the approach of providing warranted power curves by means of a simulation model are:

- Data loss by additional filtering is avoided.
- The black box simulation model can be built on aero-elastic codes as also used for the design of wind turbines. These codes are more accurate than the simplified normalisation methods included in CDV IEC 61400-12-1, Ed.2 [3] in describing the influence of meteorological variables on the power curve.
- No additional uncertainty for the impact of meteorological variables has to be put on the verified power curve, what increases the effective warranty level. However, the OEM may built-in the uncertainty of the aero-elastic code to simulate the impact of the influence of the meteorological variables in the black box model (hidden reduction of warranty level).
- The influence of seasonal effects on the power curve verification is covered, what is an advantage over warranting a site specific power curve (method 4).
- The black box simulation model can be applied for wind resource assessments in order to improve the accuracy of the expected energy yield and to get compliance with the power curve warranty.

Disadvantages of the approach are:

- It is likely that many input variables are required for the power curve verification and also if the model is intended to be applied for wind resource assessments. More expensive REWS measurements will be needed if accounting of additional uncertainties shall be avoided.
- Setting-up of the black box (or other) model creates high effort for the OEM. Furthermore, an integration of the model in the type certification process is desirable, but has so far not been realised according to the author's knowledge.
- There is hardly experience with the approach existing. Hidden issues may be present, e.g. similar to the recently discovered power curve binning issue [10], [11].
- The frame how the black box model will be provided and warranted is unclear. The full model has to be provided at latest in the frame of the negotiations of the turbine supply agreement, such that wind farm developers are able to compare the power output of competing OEMs.

8 Combining Different Approaches

As is described in chapters 2 to 7, all of the 6 presented methods to deal with the impact of meteorological variables on power curve tests in power curve warranties have advantages and disadvantage. Which of the approaches is most suitable is in general dependent on the case, e.g. whether measurements of the REWS are feasible or whether a site calibration is needed. In many cases, disadvantages of single methods can be mitigated by combining different approaches.

Often, the warranty of a site specific power curve (method 4) is most appropriate. In order to reduce the impact of seasonal effects on the comparability of the tested power curve and the warranted site specific power curve, method 4 may be combined with (method 2), i.e. data normalisation of the power curve testing data to the reference conditions of the warranted (site specific) power curve. The uncertainty of data normalising will then be much smaller than in case of a warranted power curve that does not refer to the mean site conditions. In order to further reduce high uncertainties of the normalisation procedures in case of very large deviations of the

measured conditions from the reference conditions, data filtering in ranges around the site specific reference condition may be applied as an additional measure (method 1). Such filtering will not reduce the database significantly, as the ranges of the variables can be big and centred around the mean expected conditions. Also combination of the approach of a site specific warranted power curve (method 4) with additional uncertainties of not measuring certain influential variables at all (method 3) is possible, e.g. if the warranted power curve refers to the mean site specific turbulence conditions and if the turbulence intensity cannot be determined at the power curve test. The additional uncertainty according to method 3 can then be calculated on the basis of possible seasonal variations of the turbulence intensity. Also gaps in the description of the site specific meteorological variables for the calculation of the site specific warranted power curve may be covered by the method of additional uncertainties (method 3).

9 Conclusions

Classical filtering of power curve data according to meteorological variables (method 1) has found to be problematic in practice. Data normalisation to reference conditions (method 2) or coverage of the effects by additional uncertainties (method 3) according to [3] are more suitable alternatives. However in case of method 2, the application of the REWS approach in complex terrain is hardly feasible due to very high cost, and in case of covering all effects by additional uncertainties (method 3) the total uncertainty of the power curve test may reduce the warranty level too much. The warranty of site specific power curves (method 4) is clearly preferable and can be combined with methods 1, 2 or 3 to cover deviations of the meteorological effects in the testing period from the mean conditions and gaps in the site specific description of the influential meteorological variables for determining the warranted power curve. The inner/outer range approach (method 5) sounds simple, but in reality it is no real technical solution. Warranting power curves in form of a simulation model (method 6) is promising but lacks practical experience.

10 References

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