Critical Limitations of Wind Turbine Power Curve Warranties

A. Albers
Deutsche WindGuard Consulting GmbH, Oldenburger Straße 65, D-26316 Varel, Germany
E-mail: a.albers@windguard.de, Tel: (++49) (0)4451/9515-15, Fax: (++49) (0)4451/9515-29

Summary

Wind turbine power curve warranties of many turbine suppliers became subject to increasing limitations over recent years. This more and more questions the economic value of power curve warranties. Some of the technical risks linked to the limitations remain hidden for non-experts, e.g. for turbine purchasers and sales people. Of particular importance are limitations on the validity of the warranted power curve to certain environmental conditions and turbine conditions, which often mean that the warranted power curve is not valid for the average conditions expected at a certain wind farm site, leading to too optimistic yield expectations. Turbine suppliers should warrant site specific power curves rather than generic power curves to overcome this situation. The expected revision of the power curve testing standard IEC 61400-12-1 provides guidance on how power curves can be better adjusted to site specific conditions and how uncertainties of power curves due to the impact of environmental conditions can be treated. Other critical factors of power curve warranties are mainly related to limitations on the allowed period for verifying the fulfilment of the warranty, to limitations on the selection of test turbines, to the right of the turbine supplier to optimise the turbines before the verification, to limitations on the testing procedure, to an often found artificial increase of the uncertainty of verification tests and thus to an effective (and hidden) lowering of the warranty level, to improper compensation rules and to unreasonable high limitations of the liabilities of power curve warranties.

1 Introduction

A trend has been observed over the past few years that warranties on wind turbine power curves became subject to increasing limitations. Often, neither turbine purchasers, nor sales people of turbine suppliers are aware of the risks and consequences linked to such limitations. The reported findings and recommendations are based on experience from activities as technical adviser in contract negotiations with a variety of turbine suppliers. Another technical basis of the observed effects are several power curves tests as performed for verifying power curve warranties, as well as experience as official expert in court cases.

2 Limitation on Verification Period, Test Turbines and Announcement of Tests

A power curve warranty is expected to provide a guarantee that the power output of all contractual wind turbines as function of wind speed is kept at an agreed level for the warranty period. Thus, a verification of the warranty should be possible at each turbine, where a power curve test is possible, and within the entire warranty period. Also a repetition of the power curve test should be possible for the owner after some time for the case that doubts on the power curve arise. However, this is not the case in the standard warranties as presented by many turbine suppliers. The test period is often limited to a short period after commissioning of e.g. one year, and sometimes the verification test is allowed only once. Thus, the warranty gets useless for the owner in the case that the power performance decreases with time. Furthermore, the possible test turbines are often contractually fixed. By this, verifications at other turbines, where doubts about the power curve may arise, are not possible for the owner.
Critical in this respect is also the fact that many standard warranties provide only a warranty on the mean power curve of all turbines of a wind farm as tested on a set of exemplary machines. No compensation for a significant lack of the power curve of outlier machines is provided in this case. The warranties should rather provide a power curve warranty for single turbines in addition to the warranty for the mean of the turbines, while the warranty level may be reduced for the single turbines compared to the level related to the mean power curve of all turbines. The lowering of the warranty level for single turbines can be oriented on the higher uncertainty of power curve tests for single turbines

compared to the uncertainty of a mean power curve as measured at a set of turbines. Instead, most of today's standard warranties include a lowering of the warranty level for the mean power curve as tested at a set of turbines on the basis of the uncertainty of a single power curve test.

Another limitation of many standard warranties is the obligation of the owner to inform the turbine supplier about power curve tests. Sometimes, the turbine supplier has explicitly the right to optimise the power curve before the power curve verification starts. This regulation makes it nearly impossible for the owner to proof a breach of the power curve warranty, which was present before such an optimisation. The right to optimise the power curve before the verification of the warranty seems justified only if the condition of the turbine is not in the responsibility of the turbine supplier. Otherwise, e.g. in case of the presence of full service contracts between the owner and the turbine supplier, the warranted power curve should always be reached without optimisation by the turbine supplier prior to a power curve test, and the owner should have the right to perform blind tests.

3 Limitation on General Verification Procedure

Most power curve warranties require verification tests being performed on the basis of the standard IEC 61400-12-1 [1]. This seems being justified as IEC 61400-12-1 is so far the only international standard on power curve tests and as the general procedure outlined in this standard is well accepted.

However, the standard IEC 61400-12-1 has practical shortcomings: Tests according to this standard are expensive as met masts reaching hub height are required. In complex terrain, the method is applicable only if a site calibration with additional masts has been performed prior to the installation of the turbines. Furthermore, only turbines at the boarder of wind farms can be tested. These shortcomings are a true burden for turbine owners to perform verifications of the warranted power curve at all, and sometimes power curve tests are just impossible.

Thus, alternative procedures for the verification of power curves should be seriously considered for power curve warranties, at least for cases, where an application of the standard IEC 61400-12-1 is difficult. In many cases, advanced nacelle anemometry according to the draft standard CD IEC 61400-12-2 [2] is a proper power curve verification procedure. Also the application of lidars on nacelles for power curve testing is expected to become a good alternative power curve verification procedure in the near future [3]. Especially offshore, where the application of met masts is extremely expensive, power curve verifications may be feasible also on the basis of wind measurements with a scanning lidar mounted on the turbine support structure at the tower foot. This procedure is very close to the draft revision of the standard IEC 61400-12-1 [4].

All of the alternative power curve verification procedures are still linked to higher uncertainties than the application of IEC 61400-12-1. This should be no reason for the turbine supplier to reject these methods, as the warranty level is normally reduced by the uncertainty of the power curve verification. On the other hand, the owner can consider the alternative verification procedures as trade-off of the provided warranty level and the effort for power curve verifications.

It is pointed out that the author has successfully implement alternative verification procedures in power curve warranties.

4 Limitation on Special Test Conditions

A clear trend has been observed over the past few years that power curve verification procedures as defined in standard warranties require more and more special test conditions, often far beyond the requirements defined in IEC 61400-12-1 and sometimes in contradiction to some requirements defined in IEC 61400-12-1.

Many standard warranties require additional data filtering on atmospheric conditions, like on turbulence intensity, wind shear, vertical flow inclination, air density, air temperature and wind direction. This seems justified from the viewpoint of the turbine supplier, who may intend to warrant the power curve only under well defined environmental conditions (warranty of generic power curve). However, the consequence for the turbine owner can be that the power curve tested under such special atmospheric conditions may not be representative for the wind farm site anymore and may thus be of limited value for economic considerations (e.g. wind resource assessments). Sometimes, the additional data filtering leads to very idealised measured power curves, which are just too optimistic for economic considerations, i.e. the warranty level is indirectly lowered by the filtering. In other cases, the definition of special test conditions seems being quite arbitrary, and the intention of the turbine supplier to well define the testing conditions is clearly not met. Figure 1 illustrates the effect of special data filters as defined in power curve warranties on the measurement results in terms of the annual energy production (AEP). The influence on the AEP varies approximately from -3 % to +3 %, but in the majority of the cases, the AEP is improved by the special data filtering, i.e. the verified power curve tends being overoptimistic for the wind farm site.

In order to overcome the conflict of warranting a power curve for well defined conditions (intention of turbine supplier) and getting a warranted power curve representative for the wind farm site (intention of owner), warranted power curves should be defined site specific rather than generic. The new draft revision of the standard IEC 61400-12-1 [4] provides methodologies to normalise power curve data in terms of the turbulence intensity and wind shear to pre-defined site specific conditions [5]. In terms of the air density, such data normalisation is common practice since a long time. Potential shortcomings of the normalisation procedures are covered by additional uncertainties, which again reduce the warranty level. This should be acceptable for the turbine supplier and for the owner. Another advantage of data normalisation about data filtering is that the extension of the measurement period, as sometimes caused by data filtering, is avoided.

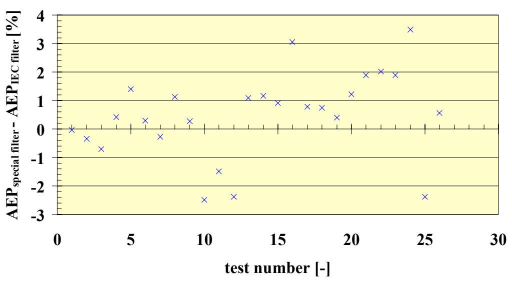

Figure 1: Influence of special data filtering as defined in power curve warranties on the measurement results in terms of the annual energy production (AEP). Shown is the AEP of the power curve under special data filtering minus the AEP of the power curve filtered according to IEC 61400-12-1 in percent for 26 test cases.

Other special testing conditions defined in some standard power curve warranties are related to certain conditions of the tested turbines. The justification of such turbine conditions must be checked case by case: It is mostly plausible to exclude special turbine conditions from power curve tests, for which the turbine supplier is not responsible, e.g. situations with improper grid conditions or noise reduced operation. Other special conditions, like e.g. automatic load reduction, may be considered as the turbine condition representative for the wind farm site and should thus not be excluded from power curve tests. A few standard warranties require even the cut-in hysteresis to be excluded from power curve verifications. This is completely unjustified, as the cut-in hysteresis can be well measured and forms a normal, although turbulence dependent, part of the power curve. Excluding the cut-in hysteresis leads to a systematic improvement of measured power curves in favour of turbine suppliers. Many standard warranties require the application of database B according to IEC 61400-12-1 instead of database A (main result according to current version of IEC 61400-12-1). Database A includes the high wind cut-off hysteresis, while database B excludes the cut-off hysteresis from power curve tests. The use of database B is supported by the fact that often not much data is present in the wind speed range where the high wind hysteresis takes place, what can lead to quite arbitrary measurement results. On the other hand, database B does not cover potential problems of a turbine to keep rated power at high wind speeds and can lead to overoptimistic AEP calculations. Furthermore, the arbitrariness of database A is expressed by a higher statistical uncertainty of the measurement, what reduces automatically the warranty level. Thus database A should be acceptable for the turbine supplier and for the owner.

Some standard power curve warranties include special conditions on the terrain at the test site, which by far exceed the requirements defined in the standard IEC 61400-12-1. Most of these requirements are rather arbitrary, what is expressed by the fact how different these additional requirements are among the turbine suppliers and how often such requirements are changed by certain turbine suppliers. Sometimes, the additional requirements make a power curve verification impossible, what invalidates the whole power curve warranty. Additional requirements on the terrain conditions are justified only at extreme sites.

Some standard power curve warranties have additional requirements on the positioning of met masts beyond the requirements defined in IEC 61400-12-1, like positioning the mast upwind of the turbine in the main wind direction or in short distances to the turbine. Such additional requirements normally intend to improve the correlation of wind speeds measured at the met mast and present at the test turbine. However, in complex terrain positioning of the mast upwind of the test turbine can be an improper choice leading to systematic errors of the site calibration. Furthermore, lowering the distance between mast and turbine is sometimes not practicable. Thus, the feasibility and appropriateness on additional requirements on mast positions must be judged for each wind farm site separately.

Certain standard power curve warranties contain additional requirements on the design of met masts, exceeding the requirements defined in IEC 61400-12-1. Most of these requirements are intended to improve the measurement accuracy, can be easily fulfilled and do not change the measured power curve in a certain direction. However, there are more critical requirements, like e.g. requesting the masts not exceeding hub height, leading to small systematic improvements of the measured power curves in the case that masts reaching exactly hub height cannot be realised.

5 Critical Aspects of Criteria of Fulfilment of Power Curve Warranties

There are still power curve warranties existing, where the treatment of the uncertainties of power curve verification tests is not defined. Experience as court adviser shows, that courts normally count the uncertainty of the verification procedure in favour of the turbine supplier if the treatment of the uncertainty is not contractually agreed otherwise. As the uncertainties of power curve verifications are considerable, the treatment of the uncertainties should always be defined in the warranty.

Most standard power curve warranties include a reduction of the warranty level by the uncertainty of the power curve verification. This principle is justified as the turbine supplier cannot be hold responsible for the uncertainty of the power curve verification. However, most standard warranties include a reduction of the warranty level by one standard uncertainty of the power curve verification. By assuming a Gaussian distribution for the uncertainty assessment, this regulation implicitly means that the true power curve of the test turbine does not reach the warranted power curve by a probability of 84 % as condition for a breach of the power curve warranty. The choice of the probability of 84 % is rather arbitrary. Reference [6] shows examples where clear shortcomings of power curves were present already in the case of power curve tests where the true power curve does not reach the warranted power curve by a probability of only 70 %. The probability of 70 % is equal to the case that the deviation of the measured and warranted power curve is 0.52 times the standard uncertainty of the test. Thus, the warranty level provided by power curve warranties should be reduced only by 0.52 times the standard uncertainty rather than by the full standard uncertainty.

Some standard power curve verifications include minimum uncertainties to be assumed for the assessment of the verified power curve. Some of these assumptions are very conservative and do lack any technical reasoning. Such conservative uncertainty assumptions lead to an improper, systematic and hidden lowering of the warranty level. The uncertainty assumptions should rather be as realistic as possible.

The standard IEC 61400-12-1 suggests a methodology how to accumulate different uncertainties of power curve measurements to an uncertainty in terms of the annual energy production. The exact formulation is given by formula E.4 of the standard IEC 61400-12-1. IEC 61400-12-1 includes further an approximation of formula E.4 given by formula E.5. Formula E.5 systematically increases the uncertainty in terms of the AEP over formula E.4 by about 10 %. Despite the fact that formula E.4 represents the exact formulation, some standard power curve warranties require formula E.5 to be applied for the calculation of the uncertainty in terms of the AEP. This is considered as being extremely unfair and reduces systematically the warranty level (clearly hidden for non-experts).

Most standard power curve warranties require the measured power curves being extrapolated to the cut-off wind speed for the comparison with the warranted power curve in terms of the AEP. This procedure is fair only if the cut-off wind speed is realistic, especially if the measured power curve is required being evaluated according to database B (high wind cut-off hysteresis not included in measurement). Most cut-off wind speeds given by turbine suppliers do not refer to 10-minute periods, i.e. most turbines effectively cut-off at wind speeds referring to 10-minute periods as relevant for wind resource assessments below the cut-off wind speeds given by turbine suppliers. In addition, most warranted power curves do not represent the high wind cut-off hysteresis of the turbine but are rather extended to the cut-off wind speed relevant for an averaging period below 10 minutes (re-cut-in not represented at all). Extending the measured power curve to this less representative cut-off wind speed leads to a reduction of the deviation of the measured and warranted power curve. This can be critical at high wind sites. Another problem of this practice is that the uncertainty calculation according to IEC 6140-12-1 refers only to the non-extended measured power curve, i.e. the uncertainty assumed for the reduction of the warranty level or for the evaluation of the criteria of fulfilment of the warranty does not fully match the compared AEP's. A more appropriate procedure is to perform the AEP calculations for the measured power curve and the warranted power curve only up to the wind speed covered by the measured power curve. By this, the AEP calculations are treated equally for both power curves, no speculation of the true power curve in the wind speed range not covered by the power curve has to be made, and the calculated uncertainty matches to the AEP-calculation.

Another critical aspect of most standard power curve warranties is that the criterion of fulfilment is defined for the mean of the measured power curves (normally for the mean AEP) by taking the mean uncertainty of the power curve tests into account, i.e. the power curve warranty is fulfilled if the mean of the measured power curves plus the mean standard uncertainty of the power curve tests exceeds the warranted power curve in terms of the AEP. In fact, the mean of the measured power curves is linked to a slightly lower uncertainty than the mean uncertainty of single power curve measurements, because some uncertainty components are independent between the single measurements (e.g. uncertainty of site effects). Thus, the criterion on the mean power curve should rather be evaluated as follows:

- The single uncertainty components should be cumulated between the single power curve measurements in a physically meaningful way in terms of the AEP by considering for each component the correlation among the measurements.
- Based on this cumulating of uncertainties, a weighted AEP should be calculated such from the single measurements that a minimum uncertainty results for the weighted AEP, rather than just calculating the arithmetic average of the measured power curves in terms of the AEP. This weighted AEP and the associated uncertainty should be relevant for the evaluation of the criterion of fulfilment of the warranty.

It is pointed out that both of the above measures are linked to a (small) reduction of the uncertainty of the mean AEP, i.e. the warranty level is slightly increased compared to the less sophisticated procedure of most standard warranties.

As is explained in chapter 2, an appropriate power curve warranty should cover also significant shortcomings of power curves of single turbines in addition to a warranty on the mean of the turbines. In terms of the criterion of fulfilment of the warranty of the power curves of single turbines, it makes sense to account the uncertainty of each single power curve test for each individual machine. As this uncertainty is normally higher than the above described uncertainty of the mean power curve, the warranty level for individual turbines is automatically reduced.

6 Critical Aspects of Compensation Rules

Some standard power curve warranties provide compensation in case of underperformance only for the warranty period. This is very critical for turbine owners if the warranty period is only in the range of 2 to 5 years, because then the warranty covers only underperformance for a small fraction of the expected lifetime of the turbines. Thus, compensation should be provided by the power curve warranty for the entire period where the underperformance is present, even if this period exceeds the warranty period. However, it is considered being fair that the fulfilment of the power curve warranty can be verified by the owner only within the warranty period.

Another shortcoming of most standard power curve warranties is that compensation for underperformance is paid only after unsuccessful trials of optimisation of the power curve by the turbine supplier. The key issue of this regulation is that the optimisation of the power curve and the re-measurement to proof the optimisation can take very long. Furthermore, quite often problems with the acceptance and interpretation of measurement results by the turbine owner and by the turbine supplier are observed. Thus, sometimes compensation gets due only after years of measurements and discussions (sometimes never), while the turbine owner is suffering from underperformance of the wind farm. In order to overcome this, compensation should be payable by the turbine supplier as soon as the owner proofs underperformance according to the procedures defined in the warranty, i.e. the compensation period should start with the start of the relevant measurements of the owner, independent from possible re-measurements or optimisation by the turbine supplier. Compensation should be payable until the turbine supplier proofs by the procedures defined in the warranty that the warranted power curve is met.

A further shortcoming of many standard power curve warranties is that the compensation for underperformance is kept proportional to the true energy yield in reference periods. If then the warranted power curve and the warranted availability level are not reached at the same time, the compensation for the underperformance of power curves is lowered by a too low availability (see illustration in Figure 2). Thus, the compensation for underperformance in terms of the power curve should be kept proportional to the true energy yield scaled by the ratio of the warranted and true availability if both warranties are not met at the same time. Alternatively, the compensation for underperformance in terms of the availability should be kept proportional to the true energy yield scaled by the ratio of the warranted and true power curve. Another, less sophisticated, method is to compensate underperformance in terms of the power curve as a lump sum proportional to the expected energy yield.

Another often observed critical aspect of power curve warranties is a very low maximum liability, e.g. of only 5 % of the turbine purchase price. Under such low liability levels, the warranty cannot be expected to compensate true significant underperformance in terms of the power curve. The liability should cover at least 20 % of the turbine purchase price.

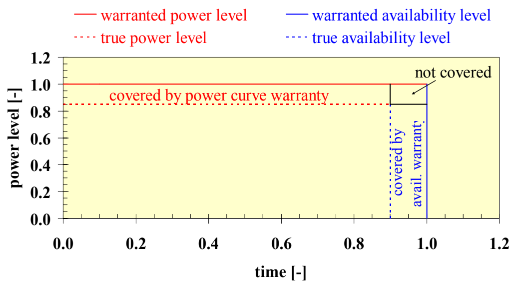

Figure 2: illustration of problem of scaling compensation for underperformance in terms of power curve and availability proportional to the true energy yield

7 Conclusions

- Many regulations offered these days by turbine suppliers in standard power curve warranties are deemed being unbalanced.
- Many power curve warranties are hardly capable to significantly reduce the risk of turbine owners linked to power curve underperformance. The associated risks should be considered in economic considerations, e.g. in uncertainties of wind resource assessments and when comparing prices of wind turbines.
- Wind turbine suppliers should rather warrant a site specific power curve, which is adjusted to the conditions expected in a certain wind farm, rather than generic power curves, which are valid only under idealised conditions. This would contribute to more realistic yield expectations of wind farms.

8 References

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