WINDebit: an alternative way to handle wind farms like power stations

Dipl.-Ing. Henning Krebs, Dipl.-Met. Eik Steinbach
Ingenieurbüro Kuntzsch GmbH, Moritzburger Weg 67, D-01109 Dresden,
Tel. ++49-351/885071, Fax ++49-351/88507409, e-mail: gutachten@ib-kuntzsch.de

Summary

Proceeding from the analogy between conventional fossil driven power stations and modern wind farms, the present paper describes the problem of the supervision of the efficiency of wind farms. The concept introduced starts already in the phase of project development and is based on the usage of wind measurements and wind flow models for the calculation of so called debit yields. Uncertainties and their interpretation are integrated to the concept.

1. Efficiency, performance and their meaning for power plants

Modern wind energy converters are like power stations: the primary energy input is transformed as efficient as possible into an output of electric energy. The behaviour of the system is described by a power curve. Usually, some additional features such as a warranted availability or different operation modes are added to constitute a comprehensive system's characteristic.

It is typical for power stations that their efficiency is kept under permanent supervision, i.e. the corresponding input and output energy quantities - in the case of fossil fuels represented by quality and volume of coal or gas and the amount of electric energy produced from it, respectively – are measured, and the result is compared to the expectations. At first view, the term '**Efficiency**' is understood to be identical to the ratio between effective energy and primary energy. This efficiency factor is restricted for thermic as well as for wind driven power stations by fundamental limits (Carnot-coefficient and Betz-coefficient) and additional more or less inevitable technical-related energy losses.

Thus, a more practical interpretation of the term ‚Efficiency' sets the amount of effective energy that was produced into relation to the corresponding energy amount that would have been produced under ideal technical conditions. In the following, this ratio is denominated by the term '**Performance**'.

The verification of the performance of the power station ‚wind farm' is – still in comparison to fossil driven power stations – influenced by the following special attributes of the primary energy *wind*:

- The amount of primary energy that flows into the system can neither be controlled (in order to achieve high efficiency) nor stored (in order to be transformed later when needed).
- The amount of primary energy that flows into the system cannot be measured offhand.

The energetic efficiency of a wind farm depends on the stochastic input of primary energy itself and is, for that reason, not a good measure for the quality of the technical system. Performance is more suitable to characterise how well the wind input is used. We define it as follows:

$$P = \frac{ACTUALyield_t}{DEBITyield_t}$$

where

ACTUAL yield$_t$ is the amount of electric energy that was earned in fact during a period of time *t*.
DEBIT yield$_t$ is the amount of electric energy, that would have been earned during the same period under ideal technical conditions.

2. Guarantees

Guarantees are agreed to describe exactly what these ideal technical conditions are composed of. To meet its purpose good guarantees should meet some requirements:

- The description of the system's behaviour should cover the complete range of operating conditions.
- The dimensions used to describe the behaviour of the system should be measurable under operating conditions.
- The basic input and output dimensions of the guarantee should directly be related to the energy input and output flows of the system.
- The regulations of the guarantee should both affect the control of operational conditions and the determination of the long-term yield expectation.

3. Power curve measurement as a tool for performance verification

Numerous guarantees describe the behaviour of single WEC's by means of a guaranteed power curve. Normally, additional regulations concerning availability (i.e. the time fraction when the WEC is technical available) are made.

In case of doubt about the compliance with the guarantee, a power curve measurement according to [1] is performed. If significant differences between measured and guaranteed power curve are detected, the decreasing value of the WEC is estimated and compensated following a procedure arranged before.

In some respect, the procedure deviates from a comprehensive check of a wind farm's performance:

- The power curve measurement can only be performed if the site conditions comply with some requirements stated in [1]. Sometimes, a site calibration is necessary before the wind farm is installed.
- The procedure is related to one (or two, at best case) WEC's placed at the border of a wind farm array. Only a part of the system 'wind farm' is analysed.
- Performance losses of the system caused by failures remain unconsidered since the measurement is designated to check the normal operation mode.
- A determination of the input energy flow from the wind measurement's results is constrained by the fact that the measurement sometimes strongly interferes with the wind farm's wake.

4. WINDebit – the concept

The procedure described in the following is intended to handle a wind farm like a power station from the very beginning. Since there is no device to measure the energy content of an air flow permanently, the input energy is represented by a classical wind measurement system. It can be the same one that was used for the exploration of the wind resource in the preparation stage of the project. The only modifications are: it is placed sufficiently far away from the WEC's position that their wake effect to the measurement can be neglected or modelled. And it is as reliable and exact as an input measure of a power station has to be (see 6.).

Fig. 1: Configuration of a WINDebit installation, consisting of a wind farm and the measurement station

The transformation of the measured wind speeds, direction, air temperatures and pressure into energy terms is done by a model. It includes the height and site transformation between the measurement's and the WEC's sites as well as yield losses due to wake effects inside the wind farm.

Setup, adjustment and application of the model are performed in two phases:

In the preparation phase of the project, the complete description of behaviour of the wind farm, related to the measurement system mentioned before, is

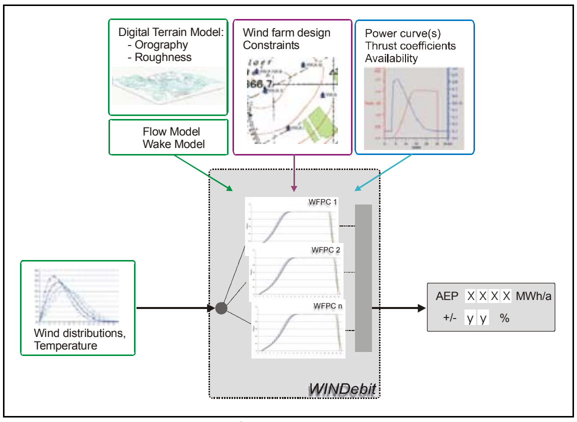

Fig. 2: Adjustment of WINDebit in the preparation phase of the project

subject to model runs and subsequent negotiations between the wind farm's operator and the supplier of the WEC's. In this phase of model adjustment, the guaranteed power curve is replaced by a wind farm power curve (WFPC), or by several of them [4]. Together with a description of availability and of additional operation modes – if existing – the behaviour of the system is described by software spreadsheets to be agreed and become part of contractual regulations. In this phase, they are used to calculate the long term average yield of the wind farm (see. Fig. 2) based on informations about the mean climate at the measurement site.

After the beginning of the wind farm's operation, the same software is used to calculate DEBIT yields to be compared with corresponding ACTUAL yields on the base of time rows measured at the station described above (see Fig. 3).

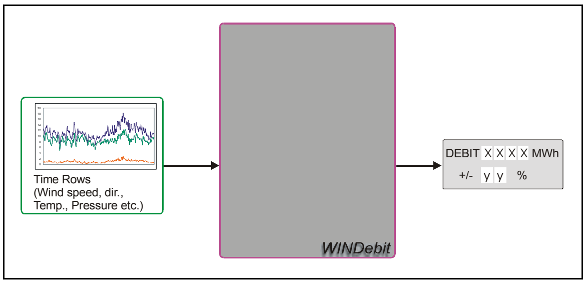

Fig. 3: Use of WINDebit for the calculation of DEBIT yields

5. Uncertainties and their effects

Measurements and models introduce uncertainties to the procedures described. Both the DEBIT yields calculated and the ACTUAL yields measured can be be characterised by their statistical distribution functions, typically Gaussian distributions parameterised by an expectation value and a (combined) standard uncertainty.

Since the uncertainty of the ACTUAL yields is given by the measurement uncertainty of the current transformers, the uncertainty of the DEBIT yields depends on several factors. The following table shows typical values to be expected for some cases.

Configuration	Typical value for relative combined uncertainty of DEBIT yields
Single WEC / Model WAsP	≈ 3 %
Small wind farm / WAsP extended / wake model	≈ 5 %
Big wind farm / use of additional WEC's for verification / WAsP / wake model	≈ 10 %

Tab. 1: Typical values for relative uncertainty of calculated DEBIT yields

For comparison purposes, the consideration of the exceedance probability of DEBIT yield together with the non-exceedance probability of ACTUAL yield can be helpful. Fig. 4 shows an example for a DEBIT yield of 1.120 MWh having a standard uncertainty of 10 % and an ACTUAL yield of 1.000 MWh having a standard uncertainty of 1 %.

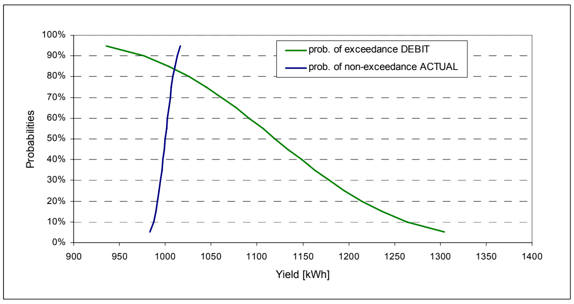

Fig. 4: Distribution functions for DEBIT and ACTUAL yields

The intersection point of both graphs shows the probability of error for the assumption that DEBIT doesn't exceed ACTUAL: it is about 84 % in the example above.

For the purpose of the calculation of financial compensations, the production difference DIFF should be the key variable: DIFF = DEBIT - ACTUAL. If DIFF is significant positive a compensation from the WEC's supplier to its operator would have to be arranged. Also DIFF has a probability distribution that can be derived from the ones described above. The interrelations illustrated in the following figure are derived from the same values for DEBIT, ACTUAL and the uncertainty of ACTUAL that were assumed for the example illustrated in Fig. 4. The values for the uncertainty of DEBIT are varied in the typical range that is described in Table 1.

The graphs in Fig. 5 can be used to find the probability of error for the assumption that DIFF is exceeded by a given value X. On the other hand, the implications of the calculation uncertainty of DEBIT to the confidence level of the decision that has to be made are visible.

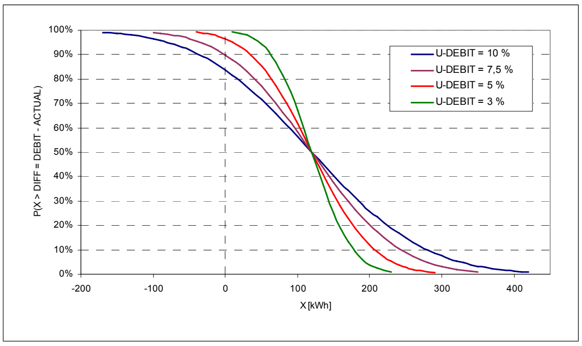

Fig. 5: Exceedance Probability of the production difference for different levels of uncertainty of the calculated DEBIT yields

Contractual regulations concerning yield differences should predefine a minimum value for the probability of error: DIFFerences recognised to be proofable with this level are to be compensated.

6. Reduction of uncertainties

The most important procedures for the limitation of uncertainties are high-quality measurements and realistic models. High-quality measurements include calibrated and redundant sensors. Target is a 100 percent availability of the measurement. Resulting requirements were already described in [2].

Necessary for WINDebit are :
- redundant heated anemometers in 2 heights
- redundant heated wind vane at the top of the mast,
- temperature sensors at the top of the mast and near ground,
- air pressure sensor,
- air humidity sensor (only for hot climates).

A realistic model for the calculation of the wind farm power curves during the adjustment phase of WINDdebit has to include the following parameters:
- obstacles,
- roughness lengths
- orography,
- thermal stratification,
- wake losses,
- air density.

A model widely used is WAsP [5]. All parameters mentioned before except stratification and air density are part of the WAsP model in a sufficient way.

The consideration of the fluctuation of air density, which amount up to about 25 percent within short operating periods of a half year or shorter, is generally necessary and can be performed according to [1].

Another option for the reduction of uncertainty within short operation periods and in case of differences between measuring height and hub height is the inclusion of thermal stratification (stability). Fig. 6

shows the influence of thermal stratification to the wind speed profile at the measuring site Bad Tennstedt (see Fig. 1). It compares the height profiles of wind speed (36 m / 50 m / 70 m / 100 m a.g.l.) with the corresponding calculation results of the logarithmic height profile, corrected by application of the Monin-Obukhov similarity theory [3]. The calculations were based only on the measurement results of 36 m and 50 m a.g.l..

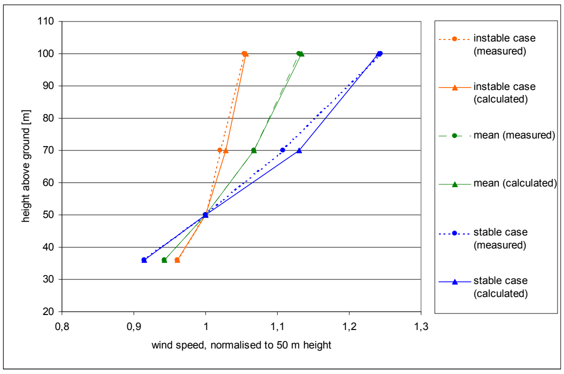

Fig. 6: Comparison of different stability situations, measured at Bad Tennstedt with calculations according [3]

7. Conclusions

Wind measurements and flow models are widely used for the exploration of the wind resource in the preparation stage of wind power projects. The concept introduced makes this experience usable for the operational stage. The complex task of the check of the wind farm's performance is traced back to only few key dimensions: the DEBIT yield and its DIFFerence to the ACTUAL yield. DEBIT yields are calculated from the results of a measurement station using a model that was justified in the project's planning phase and that is based on the method of wind farm power curves. The interpretation of measurement and calculation uncertainty results in a statistical connection between the yield DIFFerence and its probability of exceedance that can be used as base of contractual regulations.

Basic concepts of the method have already been applied to 4 wind farms in Germany. Future work will be directed at the reduction of the modeling uncertainty and the implementation of additional software routines.

8. References

[1] IEC 61400-12-1: Power performance measurements of electricity producing turbines. 1st edition 2005-12

[2] H. Krebs, E. Steinbach, W. Wilmers: How to perform complete wind measurements, Proceedings EWEC 2006, Athens.

[3] H.A.R. de Bruin, R.J. Ronda, B.J.H. van de Wiel: Approximate solutions for the Obukhov length and the surface fluxes in terms of bulk Richardson numbers. Boundary Layer Meteorol., 95:145-157, 2000

[4] J. Matos et. al.: Whole Wind Farm Warranty Verification Procedure, Proceedings EWEC 2006, Athens.

[5] European Wind Atlas. - Risø National Laboratory 1990.