Analysis of wind turbine control and performance based on time series data of the wind farm monitoring system (Analyse des Betriebs- und Leistungsverhaltens von Windparks auf Basis von Zeitreihen aus der Betriebsdatenerfassung)

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Zusammenfassung: Windenergieanlagen zeichnen im allgemeinen alle 10 Minuten einen Datensatz aller relevanten Betriebsgrößen und –messwerte auf. Oftmals wird diesen Daten nur wenig Aufmerksamkeit geschenkt. Detaillierte Analysen zeigen nun aber, dass sich hieraus sehr wertvolle Aussagen ableiten lassen.Die Genauigkeit der Messungen ist meist nicht bekannt oder sehr niedrig. Insbesondere die direkte Messung der Windgeschwindigkeit über das Gondelanemometer galt als nicht aussagekräftig. Unter der Verwendung geeigneter Verfahren lassen sich jedoch aus diesen Daten belastbare Aussagen ableiten, welche oft eine Optimierung des Betriebsverhaltens und damit teilweise erhebliche Ertragsteigerungen ermöglichen.
Die Ursachen für teilweise Projekt-bedrohende Abweichungen zwischen den realen und prognostizierten Energieerträgen liegen in ungünstigen technischen Betriebseigenschaften, ungenügenden technischen Verfügbarkeiten oder Mängeln bzw. Unsicherheiten in der der wirtschaftlichen Planung zugrunde gelegten Ertragsprognose. Eine Betriebsdatenanalyse erlaubt es zu beurteilen, aus welchen Ursachen eine solche Abweichung herrührt und wo Optimierungspotential besteht.

1 INTRODUCTION

Wind farm monitoring systems (SCADA-systems) usually record for each wind turbine (WT) a set of operational wind turbine data. Often less intention is given to this data. Careful analysis now has shown the usefulness of this data.

The accuracy of the data recorded by wind farm monitoring systems is often low or unknown. This is especially valid for the wind speed recorded on the WT's nacelle. Analysis methodologies developed by WindGuard allow the evaluation of sound results, which can be linked to an optimisation of the WT control parameters an thus to an increase of the power performance.

The origin for often precarious deviations between the real and planned energy production of wind farms can lie in an insufficient technical availability of the wind farm, insufficient WT power performance or shortcomings of the site assessment. The detailed analysis of the wind farm monitoring data is capable to serve for explaining the cause for such deviations and to identify possibilities to optimise the wind farm operation.

2 METHODOLOGY

The scope of the analysis is accustomed to the available data and the needs of the wind farm operator/owner. The performed analysis contains:

- processing and plausibility checking of SCADA-data,
- identification of different WT control settings (e.g. due to noise optimised operation, or arbitrary settings),
- Power curve evaluation by means of nacelle anemometry under full consideration of all measurement uncertainties. The methodology developed by WindGuard allows to compare power curves of the same turbine for different control settings. With additional steps also the absolute power curve of each wind turbine in a wind farm can be evaluated.
- Investigation of WT control settings (rotor speed control, pitch control, switching between generator stages),
- check of yaw control by a new approach,
- statistical analysis of WT stops caused by breakdowns or maintenance,
- evaluation of WT availability in terms of time and energy loss,
- Long-term correlation of energy production.

3 DETAILS AND RESULTS

3.1 Rotor Speed and Pitch Control

Modern wind turbines have highly adjustable control parameters. As a consequence wind farm operators are not always aware of the control settings realised at the single WTs. Also non-uniform and arbitrary control settings of WTs within the same wind farm have been found. Normally, small changes in the control settings can have a significant influence on the WT's power performance.

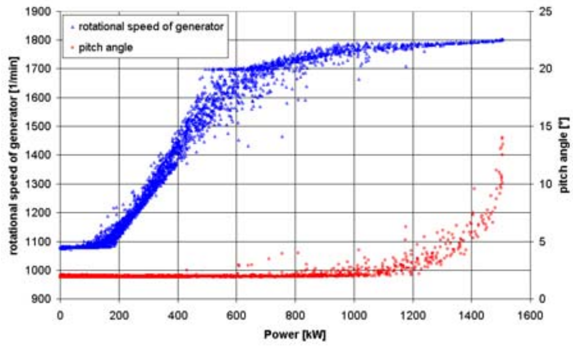


Fig. 1: Raw data of generator speed and pitch angle as function of active power (for noise optimised operation).

WindGuard starts the analysis of control parameters by identifying the measures used by the WT controller to adjust the WT control variables. Once these measures are identified, it is checked whether the control settings make sense, whether the control settings are changing over the time and whether the control settings are uniform within the wind farm. In Fig. 1 an example of 10 minute raw data is given for noise optimised WT control. At the referring WT three different control schemes have been identified within a few months of data, see Fig. 2 (without awareness of the owner).

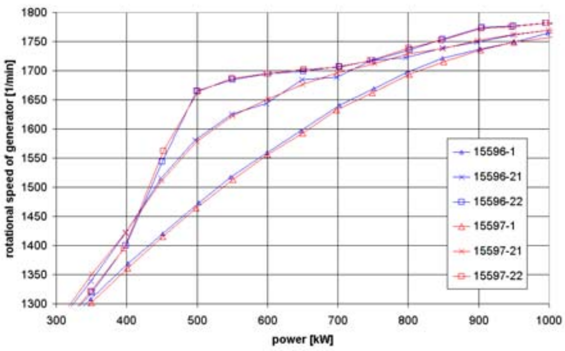


Fig. 2: Bin analysed rotor speed control. In this example three different states of the turbines were identified.

3.2 Yaw Control

The WT's yaw control is checked by means of a so-called self consistency test, which has been developed initially for the test of the evaluation sector of power curve measurements [1], see Fig. 4. This test now has been further developed for the northing of the yaw control signal. An accuracy of 5° is reached for the northing, which is of the same order than the accuracy reached by the traditional northing of the yaw signal by using a compass. By statistical analyses of the differences between the yaw signals of different turbines the proper functioning of the yaw control is evaluated.

3.3 Power Performance

The power performance of each single wind turbine is evaluated by means of nacelle anemometery as presented in reference [2] with the restriction that usually no proper correction of the nacelle anemometer to the free wind speed is available and that the nacelle anemometers are not calibrated individually by means of a wind tunnel calibration. The correction of the nacelle anemometer to the free wind speed is evaluated at one turbine of the wind farm by assuming the guaranteed power curve to be valid (Fig. 3). This correction is then used to assess a power curve in analogy to the IEC-standard [3] for every wind turbine within the wind farm and for every single control setting, that has been identified beforehand (see chapter 3.1). The wind direction sector for the data evaluation is assessed for every turbine by means of the already mentioned self-consistency test (Fig. 4), which meanwhile has also been overtaken by the MEASNET-group as a possibility to verify the evaluation sector [4]. The wind direction is evaluated by the WT's yaw signal, that has been checked beforehand as described in chapter 3.2. The air density is evaluated from air temperature signals available from the SCADA-system and from public available air pressure measurements.

The capability of this type of power performance evaluation has been evaluated by means of a detailed uncertainty analysis with the following conclusions:

- Deviations in power performance at the same turbine due to different control settings can be identified and can be quantified with a standard uncertainty below 5 % in terms of the annual energy production.
- Deviations in power performance between different turbines of same type with the same control settings cannot be identified due to the too large uncertainty. However, indications for deviations between the turbines can be seen (supported by the good correlation between the power output and the nacelle anemometer measurements). Furthermore, the comparison of power performance of different turbines would be possible if each turbine would be equipped with an calibrated anemometer and if the identical mounting arrangement of the cup anemometers would be assured [2].
- The absolute power performance of a wind turbine cannot be evaluated due to the lacking uncertainty of the procedure. The situation would change if the preconditions named in ref. [2] would be fulfilled.

The raw data plot of a power curve evaluated with the described method is shown in Fig. 5. Fig. 6 shows the deviations of power curves of the same turbine for the three control settings also demonstrated in Fig. 2. In order to judge the relevance of the deviations in power performance between different control settings in relation to the uncertainty of the evaluation, the probability that one power curve is below the other is also calculated Fig. 6.

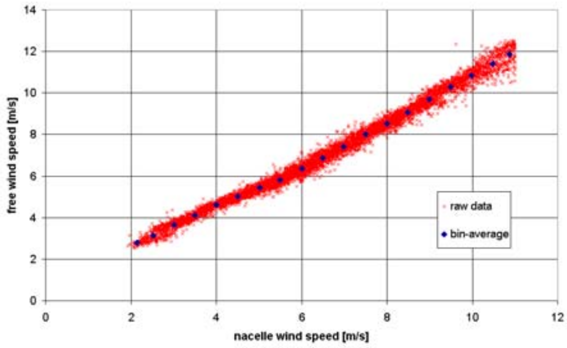


Fig. 3: Correction of wind speed measured at the nacelle to the free wind speed, evaluation from SCADA-data by assuming the guaranteed power curve to be valid.

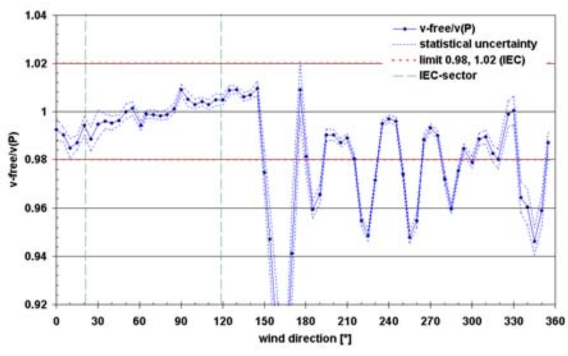


Fig. 4: Self-consistency test for assessing the wind direction sector for power curve evaluations.

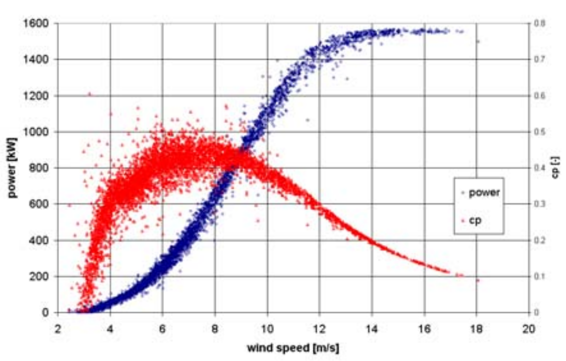


Fig. 5: Raw data plot of power curve and power coefficient

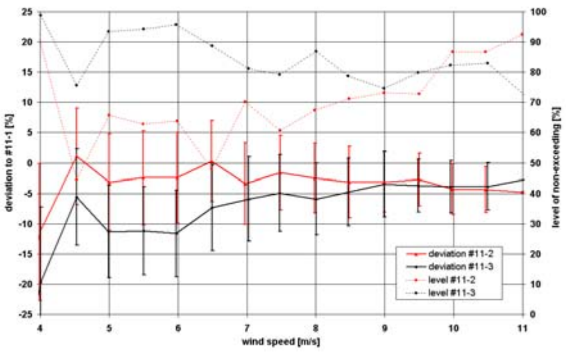
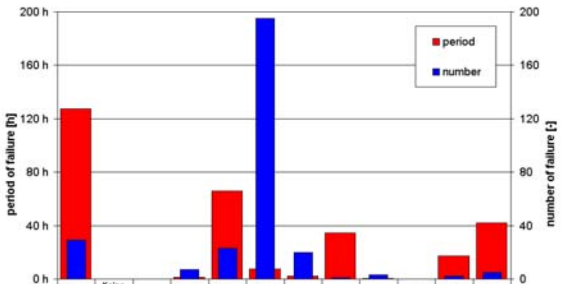


Fig. 6: Relative comparison between power curves of the same turbine for three different control settings.

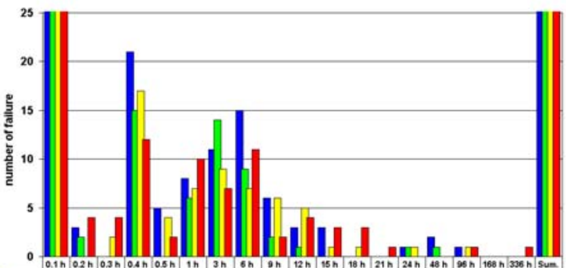
3.4 Analysis of Turbine Downtimes

The number of occurrences of turbine downtimes due to different error causes and the average duration of the single kinds of stops is evaluated from SCADA-data by analysing error codes (Fig. 7). This evaluation indicates tendencies of single components to cause turbine stopping and wind turbines with a higher than average rate of downtimes. In addition the response time of the turbine, of the technical wind farm operator of the service team on breakdowns is evaluated as shown in Fig. 8.



	Bediener stopp	Keine Kommun ikation	Bremse	Cut-Off-Wind	Hydrau lik	Auto-Wartung	Netz	Pitch	SPS	Temper atur	Elektr. Fehler	Mech. Fehler
period	127.5 h	0.0 h	0.0 h	1.2 h	66.1 h	7.4 h	2.0 h	34.3 h	0.3 h	0.0 h	17.3 h	41.9 h
number	29	0	0	7	23	195	20	1	3	0	2	5

Fig. 7: Analysis of occurrence of error causes.



	0.1 h	0.2 h	0.3 h	0.4 h	0.5 h	1 h	3 h	6 h	9 h	12 h	15 h	18 h	21 h	24 h	48 h	96 h	168 h	336 h	Sum.
WEA 1	256	3	0	21	5	8	11	15	6	3	3	0	0	1	2	1	0	0	335
WEA 2	265	2	0	15	0	6	14	9	2	1	0	0	0	1	1	0	0	0	316
WEA 3	189	0	2	17	4	7	9	7	6	5	1	1	0	1	0	1	0	0	250
WEA 4	340	4	4	12	2	10	7	11	2	4	3	3	1	0	0	1	0	1	405

Fig. 8: The Analysis of the duration of downtimes shows how long the turbine, the technical wind farm operator and the service team of the manufacturer need to eliminate the errors.

3.5 Availability

From the analysis of wind farm operational data it has been found, that the main reason for insufficient energy production in many cases was the technical non-availability of the wind farm. Different approaches are followed by WindGuard to assess the energy yield due to non-availability of wind turbines:

- by transferring the energy production data of neighbouring WT's within the same wind farm for the downtimes.
- The application of a special correction for the nacelle anemometer to the free wind speed has been found to be a proper way to evaluate the wind regime during downtimes at some wind turbine types. The corresponding energy loss is than calculated from the WT power curve.

In some cases it has been found that the technical non-availability in percentage of time was much smaller than the percentage of energy loss during the downtimes. This can be explained by the fact that some types of downtimes are more likely to occur at high winds. In the example shown in Fig. 9 the technical availability in time of a whole wind farm was 96 %, while the technical availability in terms of energy production was only 91 %.

Furthermore, it has been observed that some wind turbine manufactures tend to define some downtimes caused by technical shortcomings as states with available turbines, and thus discrepancies appear between the technical availability evaluated by the manufacturer and the technical availability relevant for the energy production.

As a consequence WindGuard has developed formulations for wind turbine purchase contracts with the following properties:

- Downtimes due to technical shortcomings are clearly defined as states of non-availability,
- Compensation claims are oriented according to the real energy losses due to non-availability (instead according to the percentage of non-availability in time).

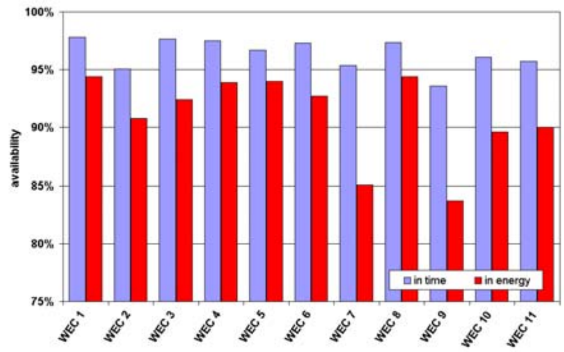


Fig. 9: Presentation of availability regarding time and energy yield

3.6 Long-term Prediction

For the wind farm owner it is important to know the average energy yield which can be expected over a long-term period. A large number of procedures exist for the long-term correlation of production data. The accuracy of the different methodologies is strongly site and case dependent and the methodology applied for long-term correlation and its uncertainty should be verified for every individual wind farm. In Germany the so-called IWET-production index [5] is often used for long term correlating the energy production of wind farms. Different shortcomings of the IWET-production index have been identified by WindGuard and are presented in reference [6]. Nevertheless, the IWET-Index has found to be useful, if different adjustments of the index as introduced by WindGuard are applied:

- A sufficient correlation between the IWET-Index and the monthly wind turbine energy production (after careful correction according to availability losses) is checked (Fig. 10).

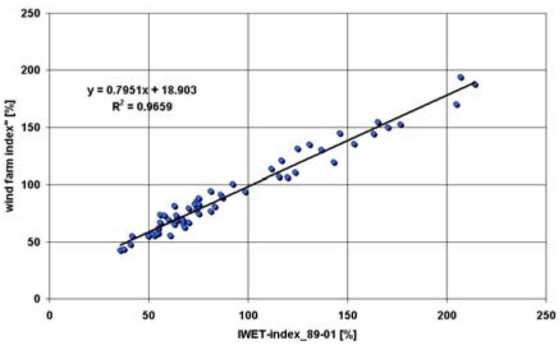


Fig. 10: Correlation analysis between the monthly energy production of a wind farm and the IWET-production index.

- Increase of the defined reference period of the index from 1989-1999 to the longest possible period.
- A correction for the IWET-Index is developed for each wind farm in order to take care for a tendency of the index to overestimate the technical available wind potential at high wind periods and to underestimate the technical available wind potential at low wind periods in some regions.
- Single months with insufficient correlation between wind turbine production and the IWET-Index are eliminated from the long-term correlation.
- The uncertainty of the long-term correlation is evaluated in every single case.

If these adjustments of the IWET-Index are applied, usually already short periods of about 3 months duration can be long-term correlated with reasonable accuracy. The outlook of energy production to be expected within long-term is done for the non-optimised wind farm and under the assumption that the potential for wind farm optimisation will be realised.

4 CONCLUSIONS

The analysis of time series data of the wind farm monitoring system allows to supervise the wind turbine control settings and to identify possibilities to optimise the wind farm operation. Energy losses due to non-optimised wind farm operation can in many cases be quantified. Furthermore, there is a high chance to identify the origin for insufficient energy production. There are already cases present, where WindGuard proved energy losses due to insufficient turbine availability and wind turbine power performance in the order of 10 %. In some cases technical availability in time was lower than guaranteed, and in addition the percentage of energy loss due to non-availability of turbines was higher than indicated by the reached availability in time.

Overall the developed methodology provides much information for whole wind farms for cost significantly lower compared to a standard power curve measurement at a single wind turbine according to the IEC-standard [3]. A power curve measurement according to the IEC-standard may be recommended in a second step after critical wind turbines in the wind farm have been identified by the methods presented here. Alternatively, absolute measurements of power curves can also be gained by applying individually calibrated nacelle anemometers with the additional pre-conditions as stated in [2].

It is further recommended to apply the methodology on a regular bases (each half year) in order to keep track with the realised wind turbine settings. The SCADA-data should be recorded without data gaps for an optimal survey.

5 REFERENCES

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