Wind Turbines with Optimized Productivity through Fleet Monitoring without Additional Sensor Technology

HERBERT FRIEDMANN, PETER KRAEMER, CHRISTOPH SCHMIDT, LUKAS BONEKEMPER and MARCEL WIEMANN

ABSTRACT

The paper is a brief presentation of a recently started research project (*WEA-produktiv*) on optimizing the electricity production of wind turbines (WT) by means of population or fleet monitoring. The project is not mainly about Structural Health Monitoring (SHM), but about finding the causes of suboptimal power production. Nevertheless, damages, manufacturing defects or inaccuracies as well as suboptimal control, etc. are some of the reasons, which can lead to a loss of power production. We assume that e.g. causes like damages, manufacturing defects or a poorly functioning of the control system of a WT are reflected to some extent in the vibration behavior of the plant. As shown below, there exist many causes for production losses. They can be most easily detected by means of population monitoring. The objective is to identify "suspect" plants in wind parks and the causes of their power production losses using only Supervisory Control and Data Acquisition (SCADA). But first, the relationships between SCADA, vibration data and power productivity must be better understood. To achieve this, a numerical (digital twin) and a data driven model (physical twin) of a so-called fleet leader are included in our calculations. In a second step, the digital twin and the data driven model will be extended to understand and to model the population of wind power plants in different wind parks. The decision whether the intended population monitoring is possible with SCADA data alone and therefore the vibration data can be omitted, will be made towards the end of the research project. This depends on the meaningfulness of the generated models.

Herbert Friedmann (corresponding author), Email: friedmann@woelfel.de, Christoph Schmidt, Wölfel Engineering GmbH & Co. KG, Max-Planck-Str. 15, 97204 Höchberg, Germany.
Peter Kraemer, Lukas Bonekemper, Marcel Wiemann, University of Siegen, Paul-Bonatz-Str. 9-11, 57072 Siegen, Germany.

INTRODUCTION: A CLEAR REFERENCE VALUE FOR ELECTRICITY PRODUCTION OF A WIND TURBINE IS MISSING

There is no clear reference value for the electricity production of a wind turbine [1]. It essentially depends on six different groups of factors:

- the turbine-specific power curve
- the site-specific conditions like wind speed, temperature, icing conditions etc.
- the control quality of the individual WT
- grid connection and control processes from the grid
- condition of different WT components: manufacturing and assembly quality
- quality and condition of the sensors included in the control system etc.

Wind turbines are long, slender structures that are highly prone to vibration. In addition, they are more or less continuously excited by the wind and in the case of offshore turbines additionally by waves as well. Therefore all these above mentioned factors are more or less reflected in the vibration behavior of WTs [2, 3]. First of all, the nominal power of a wind turbine, e.g. 3 or 4 MW, and the power-wind (P-W) diagram, in which the turbine-specific achievable nominal power is plotted above the wind speed, are decisive. Deviations of the WT-specific P-W curve, see

Figure *1*, from the nominal type-specific P-W curve can give the first indications of malfunctions. The nominal type-specific P-W curve represents the maximum amount of energy that can be produced by a specific type of WT. Besides those plant-specific parameters, there are also local, site-specific factors [1]. Wind speed and distribution is a highly variable parameter that varies greatly from region to region and changes constantly with the weather (see

Figure *2*). In addition, there are variable factors such as icing conditions that cause the system to stop if the WT is located in inhabited areas. The roughness of the earth's surface and thus the braking effect for the wind changes with the development of the vegetation over the year (e.g. leafy or bare trees, tree growth).

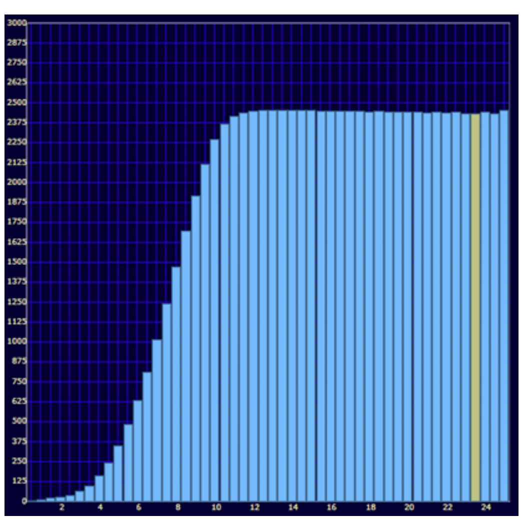

Figure 1. WT-specific P-W diagram of the Nordex N117, 2.4 MW WT in Altertheim

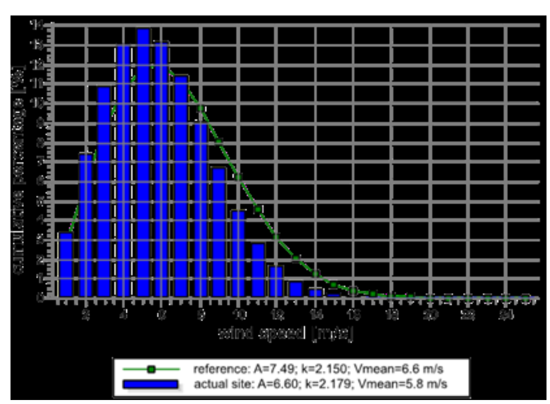

Figure 2. Weibull distribution of wind speed at the test facility in Altertheim

There are also position-related factors, e.g. if a wind turbine is located in the lee of another turbine at certain wind directions, wake effects occur, which also have a strong impact on the output. The third group of factors relates to the control quality of the turbine type and also to individual settings. These include, for example, the exact pitch angle setting and the ability to approach the optimum pitch or azimuth angle or to track it in the event of changes in the wind situation. This also includes control settings such as "wait for wind", "switch off at overspeed" etc.

The penultimate influencing factor is the grid into which the power is fed. On the one hand, the switch in energy supply from controllable power plants to volatile renewable energy sources such as wind and solar power means that power fluctuations are enormous. Overload occurs especially on low-consumption weekends when wind speed is high and the weather is sunny. This means that photovoltaics and wind turbines supply too much electricity compared to the low consumption. For this reason, WTs are switched off by the grid operator or by the turbine itself to avoid damage caused by overvoltage. In addition, there are network-related settings for the active power fed in. If - in the event of such a grid error - a WT is shut down in a controlled manner and restarted automatically after a few minutes, the power loss is limited. However, if the shutdown caused by the grid does not occur in the WT, but in the grid transfer station, a hard disconnection from the grid occurs, which can only be remedied by a manual reconnection.

The two last groups of factors include the condition of different WT components. Energy losses can be traced back to assembly and manufacturing defects, component damage and suboptimal control due to incorrect sensor information. The condition of the rotor blades, for example, plays a major role here. Have vortex generators fallen off, for example, or has the blade surface been damaged by rain and hail erosion? Or are the electrical components working properly? After all, we have to ask whether the sensors installed in the system “are telling the truth?”

Because of the superposition of these different influencing factors, there is no generally valid reference value for the performance of a WT. It is not possible to say whether the turbine is running at nominal power under the given circumstances. - or that it produces too little power compared to the nominal power and therefore needs to be maintained.

POPULATION OR FLEET MONITORING PROVIDES THE SOLUTION

Because there are no defined reference values as an assessment criterion for the optimal power production of a WT, other criteria have to be found. This can be provided by population or fleet monitoring [4, 5, 6, 7]. This is where the research project *WEA-produktiv* comes in. In this project, methods of fleet monitoring are to be developed, with the help of which suboptimal running systems can be identified, see Figure *3* and Figure *4*. All eight wind turbines in the wind park have almost the same exposure to the wind and are close together, the wind comes mainly from southwest, therefore no wake effects occur. Therefore the energy output should be very similar. But WT 7 steps out of line in the negative sense, WT 8 on the other hand in a positive sense, compared to the rest of the population which shows just slight variation. In a first step, negative examples such as WT 7 should be recognized and analyzed. Then the question would have to be asked what needs to be changed with WT 1 to 7, so that they become as productive as WT 8?

The statistical evaluation of large amounts of data and the search for correlations with certain operating states of a WT on the one hand and the analytical approach of the engineer when explaining deviating operating behavior on the other hand should complement each other in the *WEA-produktiv* project.

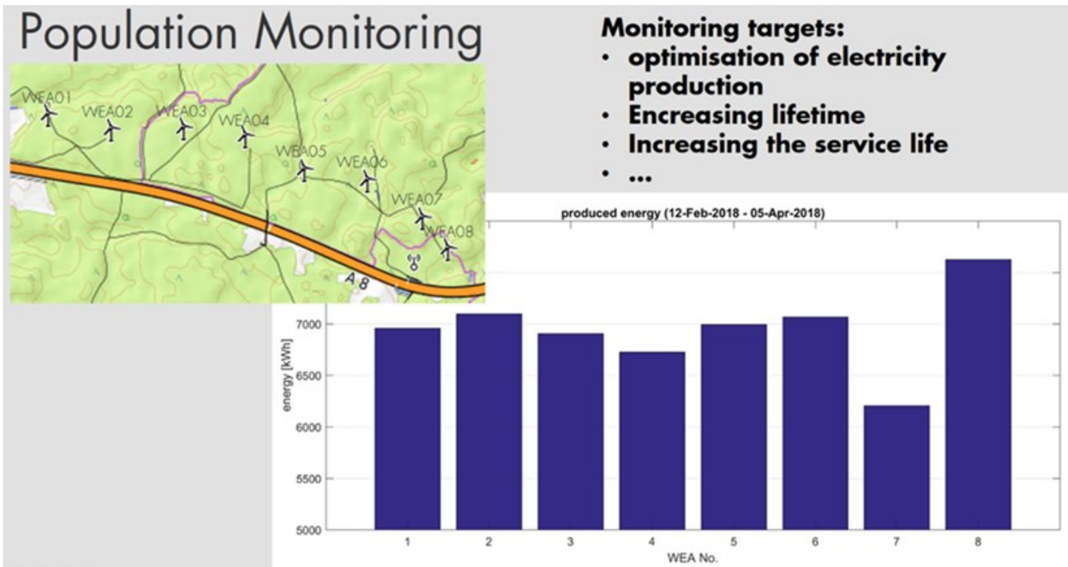

Figure 3. Greatly differing electricity generation of identical WTs in similar position

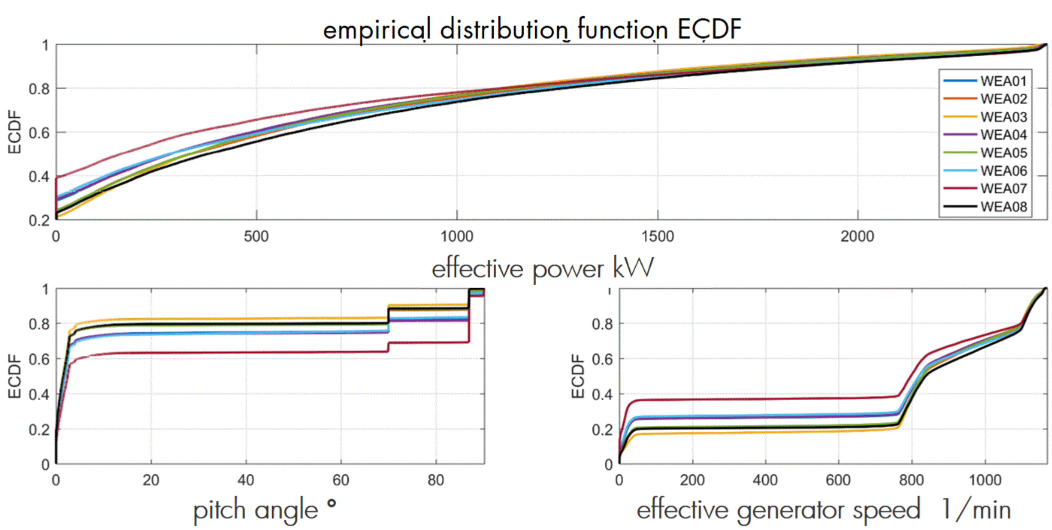

Figure 4. WEA 7 (=WT) differs from the others in all three diagrams.

On the one hand, the research can be based on a more than five-year series of measurements from more than 120 sensors in a wind turbine, see Figure *5*. Mainly accelerations, strains, inclinations and temperatures were measured. This big amount of data represents the physical twin, see Figure *6*. In addition, a simulation model is created that is based on different simulation methods from FEM to rigid body dynamics to state space models. The main application will be the analysis of time series in order to introduce damage and changes into the model.

The simulation model, which is metrologically coupled to the wind turbine, guarantees the ability to make forecasts. Deviations from normal behavior found in the monitoring data can be reproduced and understood with the simulation models. With this combination of "Big Data" and "Digital Twin", deviations from optimal system configurations can be identified at an early stage and solutions can be developed. In order to get from the individual system to the larger fleet, the combination of physical and digital twins is expanded by eight wind turbines of the same type, which also have a reduced number of vibration sensors. In an even larger circle of a few hundred wind turbines, the vibration data from the ice detection system IDD.Blade® is used to start population monitoring on a broad basis. The main scope of the project is to identify underperforming plants and the causes of power production losses using only SCADA without additional sensors (e.g. vibration sensors), [8]. This can be fully achieved only if: 1) The relationship between SCADA, vibration and power productivity can be well modelled and if the model will be able to eliminate the site-specific effects on the power productivity. 2) The vibration data can be replaced with information delivered by the digital twins.

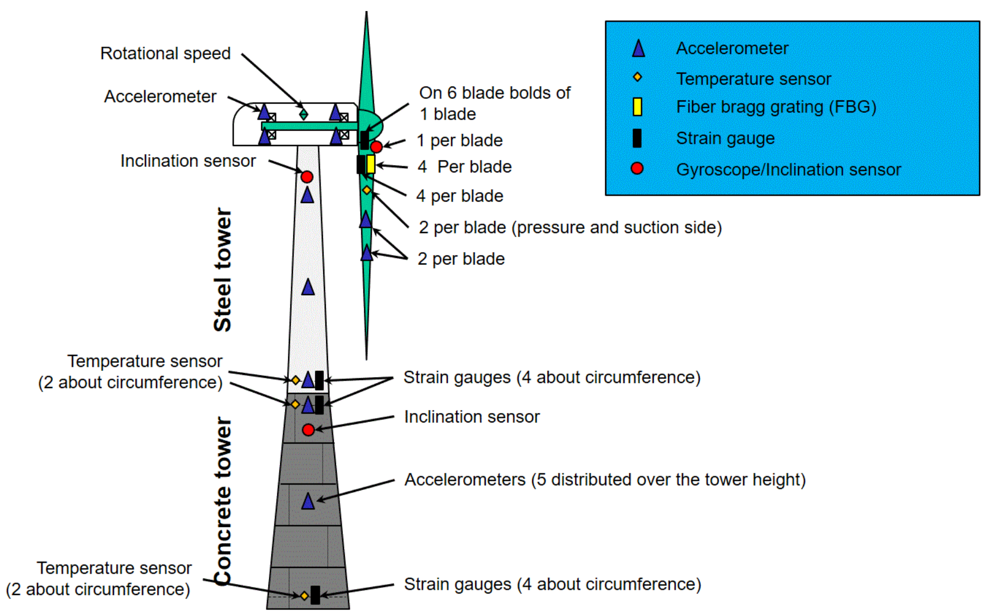

Figure 5. Test object WT Nordex N117, 2.4 MW, with approx. 120 additional sensors

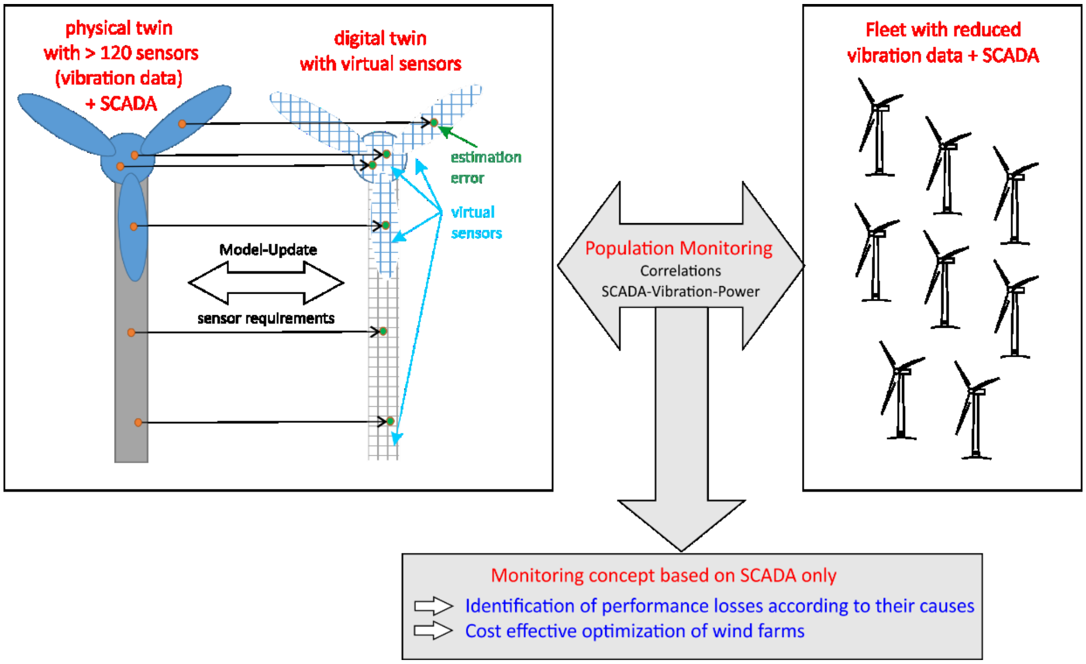

Figure 6. Rough concept for the identification of performance losses

CONCLUSION

The paper is a brief presentation of the recently started research project *WEA-produktiv* on optimizing the electricity production of WTs by means of population or fleet monitoring. The main objective is to use, if possible, only SCADA to identify underperforming plants. We have just started the work. We will keep the community up to date with the progress of the project.

ACKNOWLEDGEMENT

The authors are grateful to the Federal Ministry of Economics and Climate Protection of the Federal Republic of Germany (Project Management Jülich) for the financial support of the project *WEA-produktiv* under the funding numbers 03EE3074A and 03EE3074B.

REFERENCES

1. FRIEDMANN, H., KRAEMER, P., NUBER, A. and SCHOLZ, M., 2017: Fleet Monitoring and Site Specific Environmental and Operational Conditions in Wind Energy, 11th International Workshop on Structural Health Monitoring, Stanford University, USA
2. FRITZEN, C.-P., KRAEMER, P. and BÜTHE, I., 2013: Vibration-based Damage Detection under Changing Environmental and Operational Conditions, Advances in Science and Technology (Band 83), S. 95-104.
3. KRAEMER, P. und FRIEDMANN, H., 2015: Vibration-based structural health monitoring for offshore wind turbines structures – Experimental validation of stochastic subspace algorithms, Wind and Structures, An International Journal, Vol. 21(6), S. 693-707.
4. FRIEDMANN, H. und KRAEMER, P., 2016: Condition monitoring, structural health monitoring, population monitoring – Approach to a definition of the different concepts by means of practical examples from the field of wind energy, 8th European Workshop on Structural Health Monitoring, Bilbao
5. BULL, L.A., GARDER, P.A., GOSLIGA, J., ROGERS, T.J., DERVILIS, N., CROSS, E.J., PAPATHEOU, MAGUIRE, A.E., CAMPOS, C., WORDEN, K., 2021: Foundations of population-based SHM, Part I: Homogeneous populations and forms, Mechanical Systems and Signal Processing 148 (2021) 107141.
6. GOSLIGA, J., GARDER, P.A., BULL, L.A., DERVILIS, N., WORDEN, K., 2021: Foundations of Population-based SHM, Part II: Heterogeneous populations – Graphs, networks, and communities, Mechanical Systems and Signal Processing 148 (2021) 107144.
7. GARDER, P.A., BULL, L.A., GOSLIGA, J., DERVILIS, N., WORDEN, K., 2021: Foundations of population-based SHM, Part III: Heterogeneous populations – Mapping and transfer, Mechanical Systems and Signal Processing 148 (2021) 107142.
8. CASTELLANI, F., ASTOLFI, Davide, SDRINGOLA, P., PROIETTI, S., TERZI, L., 2017: Analyzing wind turbine directional behavior: SCADA data mining techniques for efficiency and power assessment, Applied Energy, V. 185(2), S. 1076-1086.