DOI 10.5162/sensoren2024/C1.1

Efficiency determination of wind turbines by better capturing huge torque - a crucial factor of energy transition

Dt.: Effizienzsteigerung zukünftiger Windkraftanlagen mit enormem Drehmoment - Entscheidender Faktor für die Energiewende

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Abstract

The paper describes the needs to make wind turbines a crucial contributor to energy transition- in terms of their efficiency. The presented facts and figures are supposed to be the foundation for new developments in this most important renewable energy application. The overview of future demands comprises of needs on both the mechanical side with torque and speed measurement as well as the electrical side with current and voltage measurement.

Keywords: Wind energy, renewable energy, wind turbine generator, mechanical power, electrical power, efficiency, torque sensor; power analyzer.

Introduction

By the end of 2023 the UN Climate Change Conference (COP 28) took place in Dubai, VAE. One of the most important outcomes was, that as throughout the different contribution, wind energy is the most important renewable energy source of electricity, e.g. in Germany [1].

Tab. 1: Where does our electricity come from? Report on the Electric mix in Germany in March 2024 [2].

Present status of wind energy contribution	Origin/ Location: Onshore/ Offshore	Share in electricity production (as of 3/2024)
Wind energy generation	Onshore	22%
Wind energy generation	Offshore	7%

Although the development of wind energy is subject to certain fluctuations due to different subsidies, there is constant growth in Germany [2] as well as on a worldwide scale [3].

One reason for this contribution capacity is, that wind quite steadily blows to a certain extent over all seasons and in the same way day and night. Thus, very are many reasons to safeguard further development of this type of energy generation.

As more and more wind turbine fields are planned and larger projects come into play, offshore wind turbine manufacturers employ consulting companies who mainly come from the from the shipbuilding environment, i.e. different from the onshore turbines from aerospace.

However, their “maritime approach” not always comprises with the metrological necessities. Especially, when determining the efficiency, the truth eventually come to light as values above 100% are simply impossible. So, efficiency determination impressively shows that there is no alternative to a strict metrological approach, even in a field that is so demanding on a large scale.

Growing power and increasing efficiency are general trends

To secure further developing steps in wind energy growth of wind turbine size must be assessed, and with regard to the measuring equipment especially the required torque values are important.

Therefore, a wind energy study was carried out how wind turbine power and torque may develop over the next years. Especially the metrological traceability of torque has been a topic, and whether the achieving this can be realized with a reasonable cost budget. So, the question is: How will the size of wind turbines grow over the next years?

Recently the far most offshore wind turbines however, the so called “DD” (Direct Drive) -type wind turbines [4]– also known as the variable speed direct-drive wind turbine. This Direct-Drive technology is the basis for the now very popular drive type, there a synchronous generator is used in there, directly powered by the rotor.

Because the prices for rare earths and copper – needed to build up the multipole synchronous generators - have recently fallen again, nothing stands in the way of the triumph of this type.

Subsequently offshore DD turbines will be the type that will completely dominate the world market soon and thus should be the main field of development for the worldwide wind energy contribution.

Thus, a direct-drive wind turbine’s generator has a very low rotor speed. Thus, to generate sufficient power, the torque must be tremendous.

And the other trend is, that offshore turbines are on the move forward, as they do not have the limitations as onshore wind turbines: Offshore Wind turbines face less requirements to community comfort and can thus be realized with shorter approval times. At the same time offshore DD turbines are placed in outpost far out in the sea. As they are harder to reach, they generally have to be much bigger, otherwise servicing them is simply not efficient.

We have thus worked out the general trends:
Growing power and increasing efficiency are mainly demanded by offshore DD turbines. As they must be much bigger this is leading to a growing power generation per turbine and makes increasing efficiency a profitable game.

This efficiency is determined from the quotient of output power and input power. Whether for mechanical power or electrical power, in both cases to calculate the power two variables must be multiplied. Thus, to be able to determine an efficiency of around 98%, critical parameters would have to be determined as precisely as possible. This requires a proper treatment of this measurement task to ensure smallest measuring uncertainties [4].

The torque input to nacelles is of great importance for the efficiency determination of wind turbines [5]. As turning speed of wind turbines is comparable slow, a large mechanical power can only be generated with a huge torque. And for a reliable and traceable torque measurement in nacelle test benches, the relation of nominal wind turbine capacity vs. appearing nominal torque for wind turbines is important [6]. This has been also evaluated in the survey and results will be presented.

This has been motivation to run a survey. In this survey, a clear distinction was made in between onshore and offshore turbines as well as of DD- and gearbox-type wind turbines [7]. This survey is based on a large number of different manufacturers and models, and the technical data of more than 70 turbines have been evaluated.

By considering the mechanical power and collecting information about the turning speed, it is possible to conclude on the necessary torque.

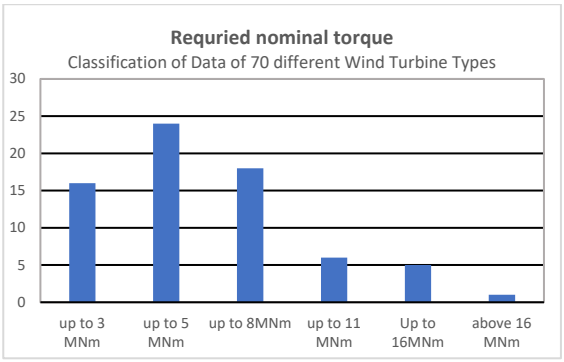

Fig. 1: *Above graph shows appearing nominal torque for wind turbines of many different manufacturers and of different nominal wind turbine capacity in their current program.*

Consequences for mechanical power determination and especially torque measurement

The majority of turbines required a torque of only up to 5 MN·m. It could be shown, that for onshore wind turbines for the foreseeable future, traceability of a nominal power of 10 MN·m for the next three years and 15 MN·m for the next six years should sufficient. Thus, as a general outcome, it can be summarized, that for offshore wind turbines will demand the larger torque. Thus, a horizon with a nominal power 20 MN·m should even be sufficient for a far-reaching future planning.

Needed are ground based test stands for this huge torque values and measures to safeguard the traceability of this value. Unfortunately, it is not possible to accomplish above requirement with a traditional back-to-back test bench, but in a metrological research project entitled” Traceable mechanical & electrical power measurement for efficiency determination of wind turbines" investigations on highest capacity torque transducers have been carried

out. This will later enable industry to measure mechanical power first time accurate at that huge scale.

But mastering the size is the be-all and end-all, and for that you need the largest torque sensors ever built. And it is indeed the largest sensors ever built by HBK. With a weight of several tons, these are extremely large. Also, the total effort required to handle them, like e.g. transport with a low-loader and heavy-duty crane required, is unique and very complex must be worthwhile for the end customer.

So far, the world's largest torque standard machine in Germany´s National Metrology Institute (PTB) in the Wind Energy Competence Center in Braunschweig, Germany. In this huge machine is our 5 MN·m torque reference transducer. It has a diameter of 1.3 m. Besides the torque, it also allows to measure the related bending moments and forces. Of course- to satisfy the needs of the before mentioned survey- larger capacities in terms of larger torque are already under discussion [8].

Consequences for electrical power determination and necessity for EMC-resistant probes for current and voltage measurement

Electrical measurement quantities have always been important, but for nowadays applications it is especially the case for measuring the parameters of electrical machines, such as motors and generators. Originally needed in Automotive Industry, main markets more and more shift to Aerospace and newly arising applications such as wind energy.

The electric power can be evaluated from the voltages and currents and achieve a better efficiency determination of electric motors and generators a much better cross-connection of mechanical & electrical side is necessary to further reduce overall measurement uncertainty.

In both the electrical and the mechanical side, the approach, to carry out a proper MU propagation, values of measured quantities are stored and analyzed in power analyzers for real data acquisition systems (DAQ systems) such as offered by the Genesis HighSpeed DAQ family of HBK.

For wind energy a further specialty comes into play. Lightning is a phenomenon that has to be dealt with in particular in wind energy production, because in addition to being classified as an electrical machine according to IEEE, the wind turbine is also a structure in the sense of civil engineering.

Further on in the electrical side the fiber optic remote probes are particularly interesting for these applications, as its EMC immunity helps ensure the correct result.

Particularly switching edges in the voltage level can lead to intense electromagnetic interference, which in turn requires an EMC-resistant design of the measuring equipment, as well as cabling and earthing concepts of the measuring environment.

Fiber optic transmission also has the advantages of low attenuation with comparatively long transmission distances, what has a particular advantage on the large spatial distances when measuring wind turbine applications. Such optical transmission can be arranged optically via the fiber optic remote probes (Fig. 2).

Fig. 2: : Fiber optic remote probes for voltage and current, Source: HBK

While voltage measurement can be realized quite easily, current measurement needs special attention.

Current measurement by using the generated magnetic field – by contrast to resistive shunt measurement method- has the specific advantage of being a non-contact i.e. isolated current measurement, so that the primary circuit does not need to be interrupted with the insertion of a lossy component like a shunt.

Fig. 3: : Fluxgate current transducer HBK CTS200ID, manufactured by DaniSense, Source: HBK

In the so called “Fluxgate” technology (Fig. 3; a combined approach with complex magnetic

performance with advanced electronics, enabling to measure current with a very high accuracy, the magnetic field created by a passing current through a primary conductor is proportional to the applied current.

Conclusions

It has been shown that efficiency determination cannot be improved by approaches to single quantities, but rather that a concerted approach to all parameters on both the mechanical and electrical sides is necessary.

On the mechanical side especially, torque can be determined much more accurate than before. MN·m torque standard is meant for the efficiency determination of wind energy generators from different manufacturers all over the world and thus is a very important basis for the transition to a low-carbon society.

Now only building up such large reference transducers is necessary, but also its traceability is important to ensure what is only possible in close cooperation between the transducer manufacturer and the National Metrology Institute.

According to the definition at VIM 3 (international vocabulary of metrology issued by the BIPM) “metrological traceability is defined property of a measurement result whereby the result can be related to a reference though a documented, unbroken chain of calibration, each contributing to the measurement uncertainty.

Thus, improving calibration and measurement capabilities is an inevitable condition for further progress in engineering [9].

Concerning the survey carried out, due to the very large amount of data that was included here, we believe that this gives a good quantification of the future challenges. The highest demands in terms of size, power and torque will be required by DD-Offshore wind turbines [10].

The determination of parameters for optimizing the efficiency of electric drives is of particular importance here, because it is important to identify and evaluate the optimization potential of electric machines, and thus on the electrical side further research should aim at highly dynamic performance measurement, highly dynamic performance analysis and investigation of dynamic load changes, meaning, with the offshore turbines getting bigger and bigger, also a rapid developed is necessary. Solutions will also be required that are specifically required to meet the requirements of wind turbine operation, such as the “remote probes” presented here.

The technology behind onshore turbines has developed rapidly in recent years, helping to dramatically lower the cost of producing wind energy. However, this will not go on without further substantial scientific work and especially players who have mastered both the mechanical and electrical aspects are required.

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