Publishable Summary for 19ENG08 WindEFCY
Traceable mechanical and electrical power measurement for efficiency determination of wind turbines

Overview

Wind energy has much potential to tackle climate change, but the efficiency of wind turbines must be improved. The overall aim of this project is to establish a reliable, practical and traceable efficiency determination method for nacelles on large-scale test benches. This will allow the wind energy sector to ameliorate the efficiency of wind turbine drive trains by comparable and repeatable testing, quicken the development cycles and shorten the time to market.

Need

The EU aims to become number one in the use of renewables, thus accelerating the energy transition towards cleaner energy sources. In 2017, the renewable with the highest capacity installations was wind power with 15.6 GW, a share of 65.3 % of all renewable power installations. To keep its top position in renewables, future wind turbines must be highly innovative, have reduced cost and improved performance. There is a clear need to quicken the development cycles, shorten the time to market of new innovations and reduce the cost of mainstream technologies in the wind energy sector. Cost reduction already started by installing test benches for nacelles and their components, but to further reduce it and ensure resilience, security and high reliability of the power production, and the development and testing process needs to be further improved.
Standardised test and validation methods are important for quality assurance. However, so far, there are no standardised tests for the efficiency determination of nacelles and their components on test benches. There is a clear need to develop traceable methods for reliable efficiency determination for nacelles prior to their installation in the field. This includes traceable mechanical and electrical power measurement in nacelle test benches.

Objectives

The overall aim of the project is to support the European energy transition towards renewable energy sources in form of wind turbines by providing a traceable efficiency determination method for devices under test on nacelle test benches and, therefore, to shorten their time to market and to ameliorate their performance. The specific objectives of the project are:

1. To carry out detailed assessment of available power and efficiency determination methods and measurements including all boundary conditions. This will also include the evaluation of power curve measurements both in the field and in test benches, and comparison of direct and indirect efficiency determination where the ratio of output to input and the power dissipation are calculated respectively.
2. To develop a good practice guide on traceable measurement methods with a target uncertainty below 0.5 % for mechanical power based on torque measurements up to 5 MN m with synchronised measurements of rotational speed up to 20 min^{-1} on the low-speed shaft respectively torque measurements up to 100 kN m with synchronised measurements of rotational speed up to 1600 min^{-1} on the high-speed shaft.
3. To develop a good practice guide on traceable measurement methods for electrical power components from the generator, the converter and the filter, which suppress harmonics.
4. To develop a good practice guide on traceable methods for the efficiency determination of devices on test benches with a target uncertainty of 1 % by combining and synchronising the mechanical and

electrical power measurements including an uncertainty model. Standardised guidelines for traceable efficiency determination on test benches will be developed.

5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain, standards developing organisations (IEC TC88) and end users (wind turbine manufacturers, wind park planners, test bench operators).

Progress beyond the state of the art

Test benches offer the advantage of recording a wide range of various data in a short period of time. However, current approaches to determine the efficiency of nacelles on test benches such as the calorimetric and efficiency method, lack either the time advantage or the traceability. This project will go beyond the state of the art by assessing in detail available power and efficiency determination methods and their boundary conditions in order to build a base for the development of a new standardised efficiency determination method performed on test benches.

Test bench operations demand highly accurate torque and rotational speed measurements traced to national standards. As stated in EMPIR 14IND14 “Torque measurement in the MN m range”, traceable torque measurement above 1.1 MN m is challenging. Moreover, no transfer standard for mechanical power measurement existed. This project will go beyond that by developing and implementing a traceable mechanical power measurement standard based on synchronised torque and rotational speed measurement on both the low-speed shaft and the high-speed shaft.

For the efficiency determination of electrical components in nacelles, such as the transformer, converter and harmonic filter, electrical power measurements under non-sinusoidal conditions at high voltage must be carried out. Commercial systems to measure electrical power need to be traced to national standards. So far, traceable in-field calibrations under realistic conditions, i.e. distorted voltage and current waveforms with amplitudes of some 10 kV and some kiloamperes are not available. This project will go beyond that by developing and implementing a traceable measurement method for electrical power components.

Currently, wind turbines are classified by their power performance which is measured in the field according to IEC 61400-12-1. This uniform methodology ensures the development and operation of wind turbines including a consistent, accurate and reproducible determination of wind turbine power performance. It represents the average power generated as a function of the mean values of undisturbed wind speed at hub height. However, this method is very time-consuming and highly affected by wind. This project will go beyond the state-of-the-art and reduce this measurement timeframe by providing the wind community with a standardised method for efficiency determination of nacelles on test benches.

Results

Detailed assessment of available power and efficiency determination methods (Objective 1)

A detailed study presenting the state-of-the-art for determining the efficiency of wind turbines in the field including a description of relevant standards such as IEC 61400-12-1, the MEASNET guideline “Power Performance Measurement Procedure” and the FGW guideline TR2 has been created. The report serves as the basis for all other objectives as it provides information on the efficiency determination in different aspects and on synchronisation technologies for different data acquisition systems.

Good practice guide on traceable measurement methods for mechanical power (Objective 2)

A 5 MN m torque transducer was calibrated up to 1.1 MN m and enhanced by two inclinometers to measure the rotational angle over time and thereby determine the rotational speed. Moreover, a new torque transducer for torque measurement under rotation has been calibrated and analysed for its application in a small-scale motor test bench. As torque measurements in test benches are not performed statically, analysis on continuous and randomised calibration loads were undertaken.

Good practice guide on traceable measurement methods for electrical power components (Objective 3)

The set-up of a reference power measurement system was defined. It is composed of a power analyser, a precision wideband high voltage divider and a precision current transducer with build-in electronics. The calibration system for the power analyser was set up. For calibrating the voltage transformers, a reference voltage divider was designed. Moreover, to measure the current, current transformers were purchased for calibrated.

Good practice guide on traceable methods for the efficiency determination of devices on test benches (Objective 4)

A practical and traceable measurement procedure for the efficiency determination of nacelles on test benches was developed and will be tested on the nacelle system test benches DyNaLab at Fraunhofer IWES, Germany, and the Center for Wind Power Drives (CWD) at RWTH Aachen, Germany. The procedure is based on EN 60034-2-1 and has been extended for more working points which are a combination of torque and rotational speed. In order to verify this newly developed measurement procedure, an already existing motor test bench with a nominal range of 200 kW was modified and extended by an additional torque transducer measuring in line with the already existing torque transducer.

Impact

Early engagement with stakeholders has been initiated by organising the project's first workshop which took place virtually and introduced the project, its challenges and the need for test bench and wind turbine manufacturers and operators, and manufacturers of measuring devices. The first newsletter for stakeholders was created and distributed to keep them in touch with the consortium. Furthermore, the project objectives were announced at a standardisation meeting of DKE K311. The first theoretical results towards traceable efficiency measurements for wind turbines on a small-scale test bench were presented at WESC 2021. Several conference peer-reviewed contributions are under way for 2021. Also, a project website has been set up and is going to be updated regularly with the project's key achievements and planned activities.

Impact on industrial and other user communities

Wind turbine manufacturers, gearbox manufacturers, test bench operators and wind park planners/operators will all benefit from the results of this project. A replicable efficiency determination on test benches will shorten the development cycles, the time to market in the wind energy sector and strengthen the competitiveness of European manufacturers of wind turbines. Although the project focuses on traceable efficiency determination of nacelles and their components on test benches, other industrial sectors can benefit from the results as well. The procedures could be adopted by rail and marine sectors, or the hydropower and gas power industry. The method adjusted to test large gearboxes or bearings could provide a more precise determination of efficiency losses, which is an estimate at the moment, and thus improve their quality. A procedure for efficiency determination in a much smaller power range will support the electrification of the automobile industry since the high rotational speed is a key parameter for eDrive applications.

Impact on the metrology and scientific communities

Within the project, calibration procedures for traceable mechanical and electrical power measurement will be developed and the associated required reference standards will be established. This will pave the way for new Calibration and Measurement Capabilities in the participating National Metrology Institutes. The scientific community, concerned with simulations, will benefit from this project by improved validations of their simulation data through more precise, reliable and trustworthy measurement results with a lower uncertainty.

Impact on relevant standards

So far, official guidelines or standards for the efficiency determination of wind turbine drive trains and their components on test benches do not exist, neither do regulations for mechanical power measurement. The results of this project, especially the results on mechanical power measurement, will input to the BIPM CCM Working Group on Force and Torque so that new regulations and standards can be developed. Testing on test benches gain an edge over field tests because they are time-saving and reproducible. The project will introduce the results to IEC TC88, which normally addresses "Measurement and assessment of power quality characteristics of grid connected wind turbines" to stimulate and support future standards. Furthermore, the guidelines on the efficiency determination and calibration of mechanical and electrical power measurement will be available as free downloads on the project's website.

Longer-term economic, social and environmental impacts

A significant long-term environmental impact would be improved predictability of the energy produced by a wind park due to the reduction of downtimes in wind turbines, ensuring that the electrical power grid remains stable when wind energy is increased. Another major economic impact will be a reliable comparability of components and entire wind turbines, as a result of a traceable efficiency determination, leading to a quicker development cycle and a shorter time to market. Moreover, a profit and loss account of a planned wind park can vary significantly for a determined efficiency of 95 % with a measurement uncertainty of 2 % of a wind turbine. For the world's biggest offshore wind park, Walney Extension in the UK, with a capacity of 659 MW, the energy amount covered by the uncertainty of the efficiency per year could power about 14,000 four-person households with an assumed energy consumption of 4000 kWh per year. A high uncertainty of the efficiency can, hence, lead to an unprofitability of the planned wind park. Only if the uncertainty of the efficiency is sufficiently low do high efficiency products become competitive.

List of publications

1. Dubowik, Mohns, Mester, Heller, Zweiffel, Quintanilla Crespo, Weidinger. (2021). 'Report on the technical requirements for the electrical power measurements and definition of the measurands for nacelle test benches' https://doi.org/10.5281/zenodo.4726089.

This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

Project start date and duration:	01 September 2020, 36 months	
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