Reliability and Energy Yield Increase of Wind Turbines as a Benefit of Dynamic Load Reduction Operation

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1 Introduction

Reliability improvement and energy yield increase are main targets during the development and operation of wind turbines. In this regard load monitoring in combination with innovative load reduction techniques gain new significance.

The wind conditions depending on the turbine location lead to different component loads of the wind turbine. It is necessary to optimize the control strategy of the wind turbines to minimize the loads and to maximize the energy yield. For this optimization the measurements of the actual drive train torque and speed are necessary.

2 Approach

The new development of a contact-free speed and torque measurement system based on standard automotive sensors provide the dynamic load data for wind turbine optimization. This so called Dynamic Load Monitoring system (DLM) provides the speeds of the low-speed-shaft and the high-speed-shaft as well as the input torque of the gearbox and the torque loading of the gearbox itself. The results illustrate high drive train torque dynamics of different wind turbines depending on the wind conditions.
The next step after load monitoring is the developed Active Torque Control (ATC) system. The basic principle of this Active Torque Control is reducing oscillations of the whole drive train by using the measured torque and speed information of the DLM-system. The measured results demonstrate the large potential of load reduction and the effectiveness of ATC in the frequency range from nearly 0 Hz to 10 Hz. By reducing these dynamical loads the reliability of the gearbox and of the whole drive train is increased. The free dynamical reserve can be used to increase the nominal torque of the turbine, which results in a higher energy yield.

3 Dynamic drive train analysis

As illustrated in Figure 1 the Dynamic Load Monitor consists of 2 sensors units, which are installed at the main shaft to measure the speed and torque of the main shaft. There is another sensor unit installed at the high speed shaft to measure the speed of the high speed shaft and in combination with the sensor units of the main shaft also the gearbox torque. The sensor units measure the speed using steel strips with an encoder structure or an existing encoder structure inside the wind turbine drive train.
These sensors are connected to the Sensor Control Unit (SCU) which provides a direct means to measure and further evaluate the torque flux transmitted through the turbine drive train. The measurements are derived from the torsion of the original drive train components observed as differential angle variations over defined components sections. Furthermore the temperature of the gearbox and the pressure of the gearbox oil supply could be monitored with the DLM-technology.

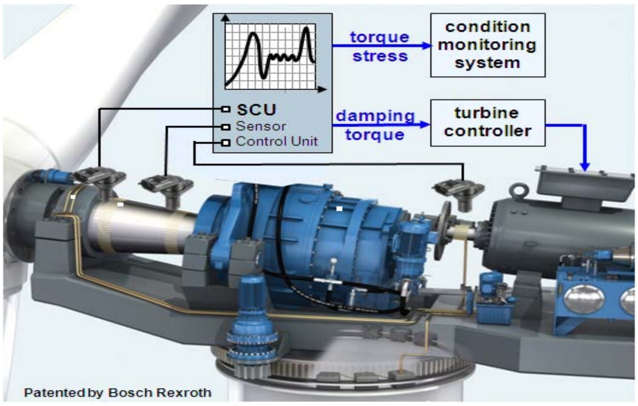

Figure 1: System structure of Dynamic Load Monitor

Measurement results

With the Dynamic Load Monitor several different wind turbines with a rated power between 1.5 and 8 MW have been monitored in the past. The measurement results demonstrate the large influence of the wind conditions and different turbine control strategies on the main shaft torque.

The measured torque of the main shaft during insufficient drive train damping is shown in Figure 2. The measured amplitude is oscillating between 80% and 120% of the rated torque. The frequency diagram of figure 2 shows clearly, that the largest amount of this torque oscillations are caused by the high oscillations of the first drive train eigenfrequency in a frequency range between 1.4 Hz and 2 Hz. This insufficient drive train damping leads to higher dynamical loads and higher component stress for almost all drive train components. Standardized wind conditions are used to calculate the design loads of the wind turbine for a service life of 20 years. In reality each wind turbine endures a slightly different load spectrum, which does not coincide exactly with the design loads (see figure 3).

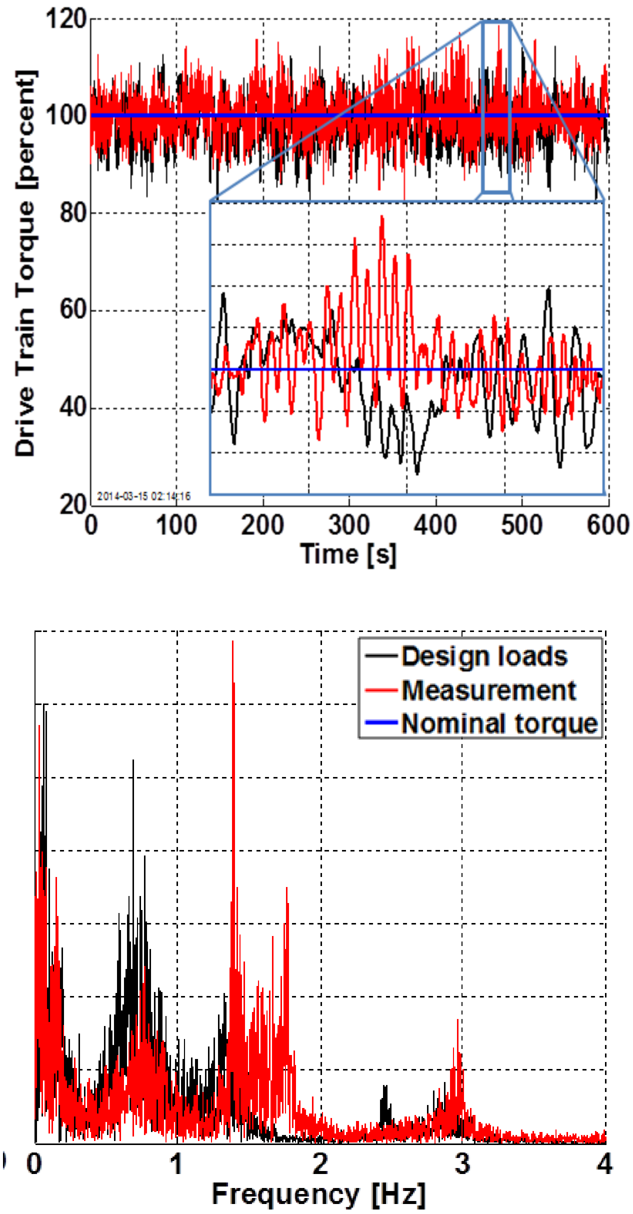

Figure 2: Comparison of drive train torque measurement and design loads (time and frequency domain)

4 Load reduction solutions

Usually the wind turbine control system adjusts the pitch angle to limit the wind turbines power to its rated value at higher wind speeds and the generator torque to maximize the energy yield in partial load. In the drive trains of wind turbines, without any kind of damping system, several eigenfrequencies and torque oscillations in different frequency ranges will occur unavoidably.

The “state of the art damping” to reduce oscillations of the drive train is to calculate an additive generator torque from the generator speed using a band-pass filter on the first torsional eigenfrequency. This design was recommended in [BOS00] and is patented and used by turbine manufacturers in different variations.

Principle of Active Torque Control

The real time measurement data provided by the DLM can be used for Active Torque Control to reduce the torque and speed oscillations by actively adjusting the generator torque to the incoming wind loads. A comparison between the different drive train damping strategies is shown in figure 4. In Figure 4 the drive train torque shows significant reduction of torque oscillations with the state of the art damping in the frequency range between 1.5 Hz and 2.2 Hz. Besides this oscillation reduction for the first torsional eigenfrequency, in most turbines there is an increase of torque oscillations outside this frequency range.

When using Active Torque Control based on the real drive train torque and speed measurement, there is a better damping of the first torsional eigenfrequency than with a conventional design using a band-pass filter [FRE11]. Furthermore ATC works in a wide frequency range from about 0.1 to 10 Hz. This is why ATC is also able to dampen the oscillations of the drive train in combination with blade oscillations at about 3.5 Hz and oscillations caused by wind speed fluctuations at about 0.1 to 0.2 Hz. In addition to that the speed variable frequencies (also called 3p; for 3 times per revolution) at about 0.7 Hz can also be reduced significantly. Furthermore ATC was installed and tested on a multi-megawatt wind turbine. Measurement results with ATC are shown in [SCH13].

Theoretically more than 80% of the damaging loads, relating to hertzian pressure inside the gearbox, are resulting from a torque loading of more than 95% of the nominal torque. Therefore torque oscillations as illustrated in Figure 3 result in high damaging loads, which could be avoided by using Active Torque Control. With ATC the dynamic torque oscillations can be reduced to a minimum, which results in less loading for all torque stressed components. The comparison in the measurement for a wind turbine shows a reduction of the damaging loads for the gearbox with Active Torque Control, which can be used for an increase in energy yield. Furthermore this reduction of dynamics ensures a higher reliability of the drive train components.

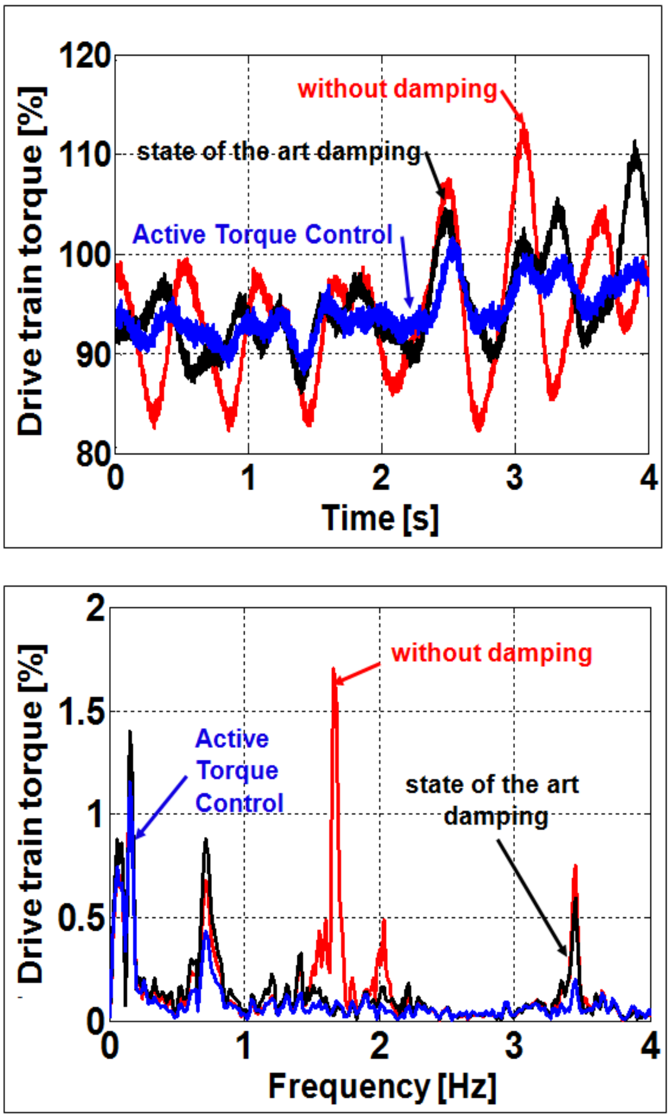

Figure 3: Comparison of drive train damping strategies in time and frequency domain

5 Conclusion

As illustrated in the measurements the Dynamic Load Monitor provides a direct means to measure and further evaluate the torque flux transmitted through the turbine drive train. The results illustrate the high drive train torque dynamics of wind turbines depending on the wind conditions and on different drive train control strategies. The measured results demonstrate the large potential of load reduction and the effectiveness of Active Torque Control in the frequency range from nearly 0 Hz to 10 Hz. By reducing these dynamical loads the reliability of the gearbox and of the whole drive train is increased. The free dynamical reserve can be used to increase the nominal torque of the turbine, which results in a higher energy yield.

6 Learning objectives

The drive train design loads of wind turbines are different to real loads during operation. By measuring the real drive train loads with the Dynamic Load Monitoring system it is possible to optimize the turbine control strategy. The result of this optimization is a higher energy yield and simultaneously a reduction of dynamical loads and therefore higher reliability of the wind turbines.

7 References

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