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Testing and Modeling of a 3-MW Wind Turbine Using Fully Coupled Simulation Codes

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Figure 1. (left) ALSTOM ECO-100 turbine at NWTC. (right) turbine simulation in S4WT.

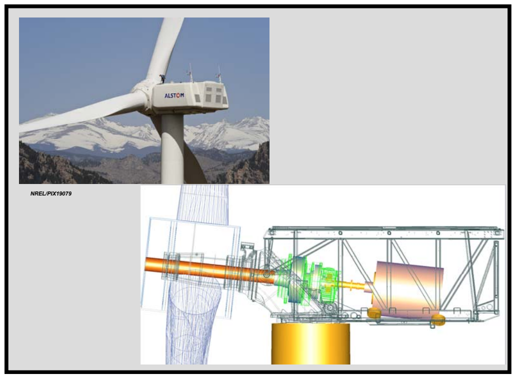

Figure 2. (left) Close-up of the ALSTOM ECO-100 at NWTC, (right) drivetrain view of the turbine model in S4WT.

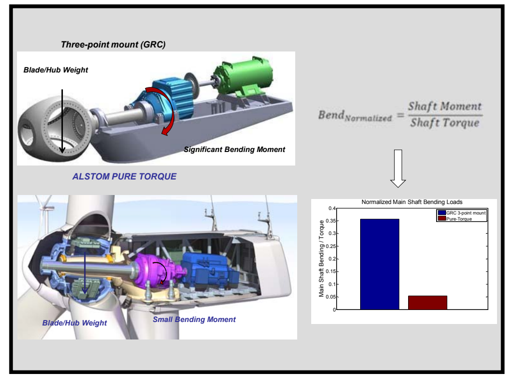

Figure 3. (top left) Comparison of a three-point mount drivetrain to (top right) the ALSTOM PURE TORQUE concept. (bottom) Comparison of the maximum normalized bending loads for the two drivetrain configurations.

Abstract

NREL, in collaboration with ALSTOM Wind, is studying a 3-MW wind turbine installed at the National Wind Technology Center (NWTC). The project analyzes the turbine design using a state-of-the-art simulation code validated with detailed test data. This poster describes the testing and the model validation effort, and provides conclusions about the performance of the unique drivetrain configuration used in this wind turbine. The 3-MW machine has been operating at the NWTC since March 2011, and drivetrain measurements will be collected through the spring of 2012. The NWTC testing site has particularly turbulent wind patterns that allow for the measurement of large transient loads and the resulting turbine response. This poster describes the 3-MW turbine test project, the instrumentation installed, and the load cases captured. The design of a reliable wind turbine drivetrain increasingly relies on the use of advanced simulation to predict structural responses in a varying wind field. This poster presents a fully coupled, aero-elastic and dynamic model of the wind turbine. It also shows the methodology used to validate the model, including the use of measured tower modes, model-to-model comparisons of the power curve, and main shaft bending predictions for various load cases. The drivetrain is designed to only transmit torque to the gearbox, eliminating non-torque moments that are known to cause gear misalignment. Preliminary results show that the drivetrain is able to divert bending loads in extreme loading cases, and that a significantly smaller bending moment is induced on the main shaft compared to a three-point mounting design.

Objective and Approach

The objective of the cooperative research partnership between NREL and ALSTOM is to assess the performance of the PURE TORQUE [1] concept in the ALSTOM 3-MW wind turbine. To accomplish this, we instrumented the turbine from the blade roots to the gearbox and created an advanced numerical model of the turbine, as shown in Figures 1 and 2. We then analyzed and compared the performance findings from both testing and simulation to create a full understanding of the drivetrain.

Drivetrain Concept

The ALSTOM PURE TORQUE concept is a unique rotor support system that was designed to improve gearbox reliability by diverting non-torsional rotor loads directly to the structure. The rotor is mounted on a tubular front frame through a couple of tapered roller bearings, and the main shaft is connected to the rotor through an elastic coupling located at the foremost side of the turbine, as seen in Figures 2 and 3. The shaft floats between this elastic coupling and the elastic gearbox support and can accommodate misalignments and frame deflections to avoid unwanted constraint forces. The gearbox is therefore expected to operate under nearly pure torsion.

Code Validation

We built a full turbine model using Samcef for Wind Turbine (S4WT) software. The tower, blades, and drivetrain shafts are modeled with beam elements, and super elements are generated from finite element models for more complex structures such as the gearbox housing, carrier, bedplate, and nacelle. The comparison of the power curve to Bladed in Figure 4 shows good correlation.

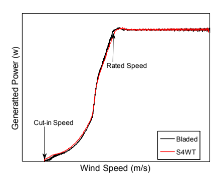

Figure 4. Power curve comparisons for S4WT and Bladed.

As part of the effort to validate the global dynamics of the model, the first tower bending mode frequency is compared to field data in Figure 5. The model predicts the frequency within 0.1% of the measured result. Good knowledge of the nacelle's entire weight and the foundation's stiffness allows the dynamics to be accurately captured in the model.

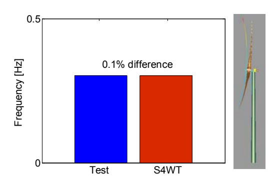

Figure 5. (left) Comparison of first tower bending eigen-frequency. (right) Visualization of eigen-mode displacements.

To assess the effectiveness of the PURE TORQUE concept, we evaluated the moment distribution along the main shaft in the model for a number of loading cases, including normal operation, a pitch stuck condition, and an emergency stop. For all of these cases, we observed that the main shaft bending condition is mostly a result of the shaft's weight, and that, in extreme cases, the soft hub coupling does not induce significantly higher moments on the shaft. The results are shown in Figure 6.

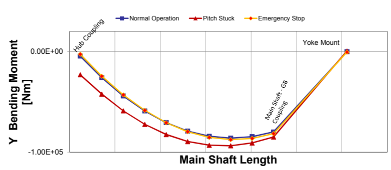

Figure 6 Main shaft moment distribution for various simulated load cases.

As a further point of comparison, the maximum main shaft bending magnitude for the ALSTOM ECO-100 in normal operation is normalized by the torque rating of the machine and compared to the normalized main shaft bending of the Gearbox Reliability Collaborative (GRC) 750-kW gearbox. The GRC gearbox features a typical three-point mounted drivetrain. This comparison in Figure 3 shows that the main shaft bending is a markedly lower percent of torque in the PURE TORQUE drivetrain concept. Although it is typical to see main shaft bending around 35% of main shaft torque in the GRC field testing, the ECO-100 model predicts approximately 5% during normal operating conditions.

Instrumentation

The ECO 100 wind turbine at NREL was instrumented to measure loads in the load path from rotor to foundation:

- Flap and lead-lag moments on all three blade roots
- Bending moments in the front main frame
- Bending moments and torque on the shaft
- Bending moments at the tower base

In addition to measuring the loads above, proximity sensors were mounted to measure gearbox motion with respect to the main frame, and an accelerometer was placed in the high-speed section of the gearbox housing to monitor gearbox vibrations. The installation of blade root instrumentation is shown in Figure 7.

Figure 7. Blade root strain instrumentation.

Conclusions

Although the project is still in its early stages, preliminary conclusions include:

- The S4WT model compares well with the Bladed model for predicting the power curve of the machine.
- Comparison of the first eigen-frequency shows good correlation with measurements.
- Modeling results show that the hub coupling is able to isolate the main shaft from a large amount of the moment reaction normally associated with emergency stop and pitch error loading cases.
- Initial modeling results show significant decrease in the main shaft bending when compared to the three point suspension topology.

Future Work

Future work will include increasing model fidelity and conducting more in-depth model-to-test comparisons as the project continues. Future tasks include:

- Increase model fidelity of the gearbox to include gear microgeometry and detailed bearing stiffness models
- Perform a detailed load path validation with measurement and simulation data to further characterize the performance of the PURE TORQUE system
- Perform measurement load cases for extreme loading events (emergency stops, one blade stuck in pitch)
- Conduct model-to-test comparisons of gearbox displacement, vibration and loading.

[1] PURE TORQUE is a registered trademark of ALSTOM.

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