1. Introduction

As wind turbines increase in size, combined with increased lifetime demands, new methods for load reduction need to be examined. One method is to make the yaw system of the turbine more flexible and thereby dampen the loads to the system, which is the focus of the current paper.

By utilizing the HAWC2 aeroelastic code and an extended model of the NREL 5-MW turbine combined with a simplified linear model of the turbine, the parameters of the soft yaw system are optimized to reduce loading in critical components.

Results shows that a significant reduction in fatigue and extreme loads to the yaw system and rotor shafts when using the soft yaw drive concept compared to the original stiff yaw system.

The physical elements of the hydraulic yaw system are furthermore examined for a life time of 20 years. Based on the extrapolated loads, the daily and week cycles show that it is possible to construct a hydraulic soft yaw system, which is able to reduce the loads on the wind turbine significantly.

A full scale hydraulic yaw test rig is available for experiments and tests. The test rig is presented as well as the system schematics of the hydraulic yaw system.

2. Advantages of hydraulic yaw systems

The hydraulic yaw system will operate as a static suspension system on a car, hence leading the loads away from the wind turbine structure and into the hydraulic structure where it can be dissipated as heat.

Implementation of the hydraulic yaw system leads to the following advantages:

- Reduced system in different operating modes.
- No yaw per load at all.
- Save the cost of the yaw brake.
- Deflect load from the wind turbine.
- Load reduction: Both ultimate and fatigue loads are reduced by a combination of stiffening the yaw system and softening the yaw system.
- No breakable electrics due to absence of yaw brakes.
- No detection of yaw error based on pressure loss.
- Simplification of electrical system, if electrical yaw control is utilized.

3. Wind turbine model

The model parameters are based on data from the NREL 5-MW turbine. The parameters of the hydraulic yaw systems are based on the extrapolated load and the duty cycle on the full scale test rig shown in figure 6. The test rig is a combination of the test rig in [1] and figure 1.

The overall parameters and coordinate system may be found in table 1 and figure 1.

4. Optimization of Stiffness and Damping

As described the objective of the soft yaw system is to lower the ultimate and fatigue loads on the turbine by shifting the moment of inertia in a controlled manner. The movement is controlled by the stiffness, K, and damping, B, of the system. To find the optimal solution for this, a graphical solution method is chosen. It is desired to minimize both extreme loads and fatigue loads, why the objective is to minimize

\[ f(B,K) = M_{extr} + M_{fat} \]

where \( M_{extr} \) is the extreme load on the yaw system and \( M_{fat} \) is the equivalent fatigue load on the yaw system. \( f \) is based on natural frequencies and Peterson’s partial damage hypothesis.

To find an optimal value of both \( K \) and \( B \) HAWC2 is utilized. At 24\([m/s]\) respectively, and normal turbulence, model HAWC2 simulations with different variations of \( K \) and \( B \) are performed. The values of \( K \) and \( B \) are selected to fit a damping ratio of 0.5 of a simplified linear model, see Stubkier and Pedersen [10] for a more profound analysis.

The results from HAWC2 are shown in figures 2 and 3. The simulations are done in the yaw stiffness.

5. Results I

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Figure 2 clearly shows how the cost increases with smaller angular movements for simulations at 24\([m/s]\).

Hydraulic soft yaw system for load reduction

8. Test rig

The concept of the soft hydraulic yaw system is tested on the full scale test rig, shown in figure 6. The test rig consists of 8 hydraulic internal gear motors, which represent the hydraulic soft yaw system in combination with hydraulic accumulators.

- Hydraulic motor/pumps - 32 ccm
- Pressure relief valve - for voltage and frequency
- Hydraulic accumulator - for system monitoring
- Flowing valve - for cooling and cleaning of the oil
- Pressure transducer – for system monitoring
- Hydraulic motor/pumps - 32 ccm

9. Results II

To collect the 20 year duty cycle data in the form of speed and load of the hydraulic motors and the given the different DLCs, ranging from 1.25 to 0.90, and combined with weighing them according to the PDF and extrapolate the data for the 20-year period.

Table 2: Summary of fatigue load reduction from simulations

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Fatigue Reduction [%]</th>
<th>Ultimate Reduction [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft yaw</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>Stiff yaw</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

10. Conclusion

The poster presented the advantages, turbine modeling, optimization and results from the soft hydraulic concept. Further a full scale test rig is presented for further testing. It is concluded that the results from the loads extrapolated over 20 years shows huge reductions in fatigue and ultimate loads on the wind turbine. Especially the fatigue loads on the yaw system are reduced significantly.

On the hardware side duty cycles for a hydraulic system consisting of eight motor/year units is presented. This is done for a simple model including friction. Finding the right hardware, which can handle 20 years of operation with the presented duty cycles will lead to significant load reductions on the wind turbine structure.

This might increase the cost of the yaw system compared to an original stiff system, but the total cost of ownership for the wind turbine is expected to be reduced significantly.

Further reading