A Two-Bladed Teetering Hub configuration for the DTU 10 MW RWT: loads considerations

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Abstract

As the size of wind turbine rotors continuously grows, the need for innovative solutions that would yield to lighter rotor configurations becomes more urgent. Traditional wind turbine designs have favored the classic three-bladed upwind rotor configuration. This work presents instead a concept study on an alternative downwind two-bladed rotor configuration.

The study is based on the DTU 10-MW Reference Wind Turbine (RWT) model. The aerodynamic planform of the original rotor is maintained, and the rotor solidity is kept by increasing the blade chord by 50%. The configuration allows saving 30% of the rotor weight and material, but implies several drawbacks: lower power output due to increased tip losses effects, and increased loads variations and hence fatigue damage.

To mitigate the load amplification caused by the interaction between the tower frequency and the rotational forcing, the tower mode frequency is lowered with a modified lower stiffness distribution. The loads caused by the aerodynamic unbalance are instead addressed by introducing a teetering hub configuration. The load alleviation potential of the teetering hub, and the required teeter angle range are evaluated for different stiffness values of the teeter bearing.

Objectives

• Propose a two bladed rotor design for the DTU 10 MW RWT
• The first design iteration is based on constant solidity scaling of the rotor geometry
• Quantify the power losses due to increased tip-loss effects
• Quantify the increase of the fatigue damage loads, and identify its sources
• Investigate aeroelastic interaction between tower frequency and the dominant 2P rotational forcing
• Investigate the load alleviation potential of a teetering hub configuration

Methods

2 Bladed Rotor Design:
Constant solidity approach:
- Chord length and blade geometry scaled by 1.5.
- Blade structure approximated to a spar with rectangular cross section [2]
- Cross section thickness reduced by 1/1.5
- Same blade weight, blade stiffness increased by 1.5

With constant solidity design:
- Same aerodynamic design of the rotor
- Same Tip Speed Ratio, same control setup
- Rotor mass reduced by 33% [3]

Simulation Setup:
- DTU 10 MW Reference Wind Turbine (RWT) [6]
- Aeroelastic code HAWC2 [1] (BEM and multibody)
- Wind field conditions as IEC normal operation conditions [3]
- Mean wind speed at hub height of 10 m/s.
- Mann’s 3D turbulent wind fields [4], TI 0.1834 (IEC class B).

Results

The proposed rotor configuration reduces the weight of the rotor by one third, but has significant drawbacks: reduction of power output, and load increase.

Power reduction due to higher tip loss effects:

Due to increase tip losses effects, the Cp is reduced by 4.2% according to BEM, 3.5% in 3D CFD simulations performed with Ellipsys.

The tip losses yield to a 2% reduction of AEP. A further 1% is lost due to increased tower shadow effects in the downwind configuration.

Conclusions and future work

The proposed two bladed downwind rotor design reduces the rotor weight by approximately 30%, but has several drawbacks: 3% reduction of the energy output due to increased tip losses, and increased DEL on blades, shaft, and tower.

A significant DEL increase in the tower can be avoided by separating the tower and the 2P frequencies, a softer tower structure would achieve so but may complicate the control tuning and interact with wave loads. A teetering hub configuration alleviates the loads on the shaft and on the blade but might reduce tower-blade clearance.

To conclude, the proposed constant solidity two-bladed rotor design has drawbacks unlikely to be compensated by the weight reduction.

Future work should consider alternative two-bladed rotor designs, with lower rotor solidity, and higher rotational speed. A lower solidity design would achieve lower loads on the shaft and on the blade but might reduce tower-blade clearance.

References