Torque-Matched Aerodynamic Shape Optimization of HAWT Rotor

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Introduction

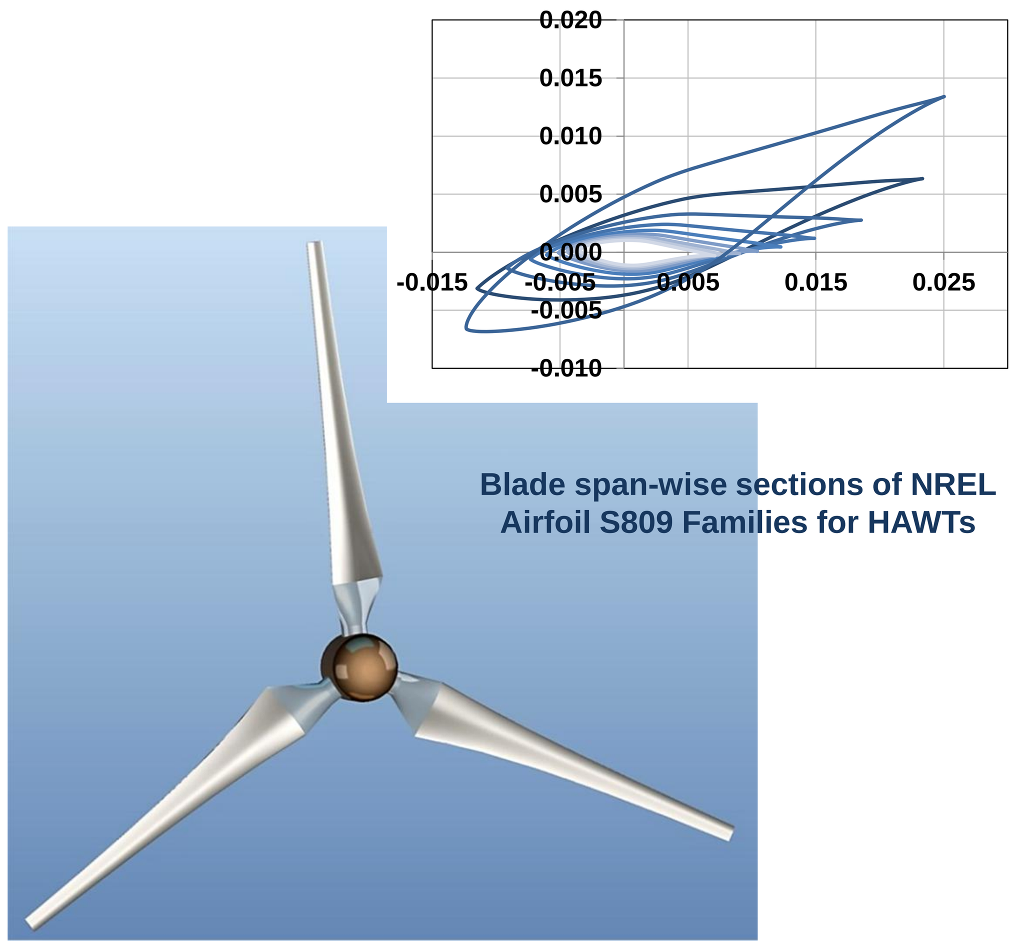
Motivation

- Designing an efficient HAWT rotor by combining the conventional design theories.
- Enhancing the HAWT performance with the aerodynamic shape optimization methods.
- Applying the optimization code into a laboratory scale HAWT.
- Matching the torque of the rotor with that of the selected generator during optimization.
- Virtual testing of the rotor by matching the torque to that of a generator.
- Validating the theoretical optimized rotor with numerical simulations.

Approach

Numerical Optimization of the turbine Rotor blades with Betz, BEM & Schmitz Theories

Initial rotor design



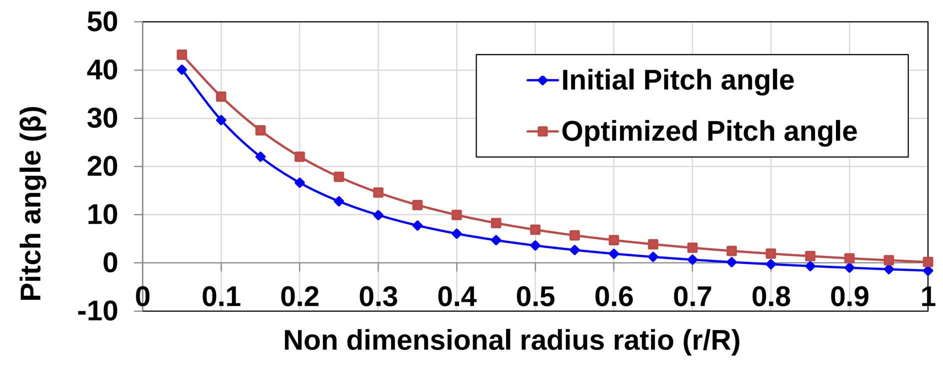
Blade span-wise sections of NREL Airfoil S809 Families for HAWTs

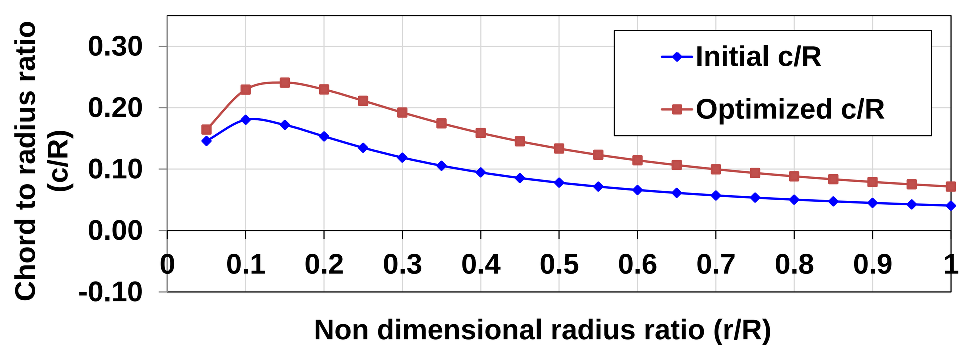
Initial design rotor with Betz, BEM & Schmitz Theories at tip speed ratio =7

Numerical optimization

Gradient based Optimization

Objective :Maximum Power Coefficient (Cp)
Constraint :Generator Torque
Parameters :Wind velocity & rotating speed
Algorithem :Activ-Set





Chord and pitch angle distribution

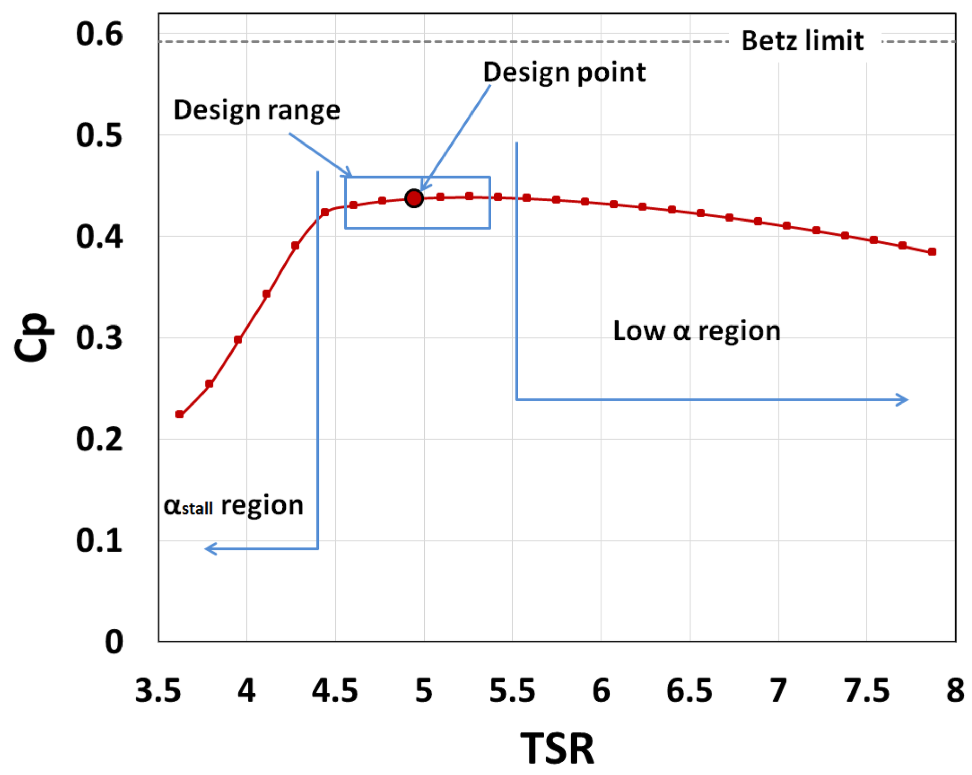
Optimized rotor

Torque-matched optimized rotor

$v[m/s]$	$\omega[rad/s]$	$\lambda[-]$	$C_p[-]$
15.32	302.22	4.93	0.44

Results

Optimization testing

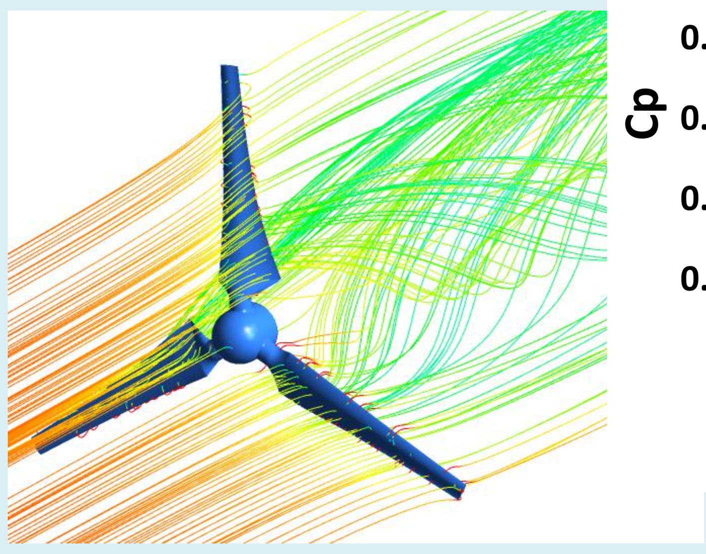


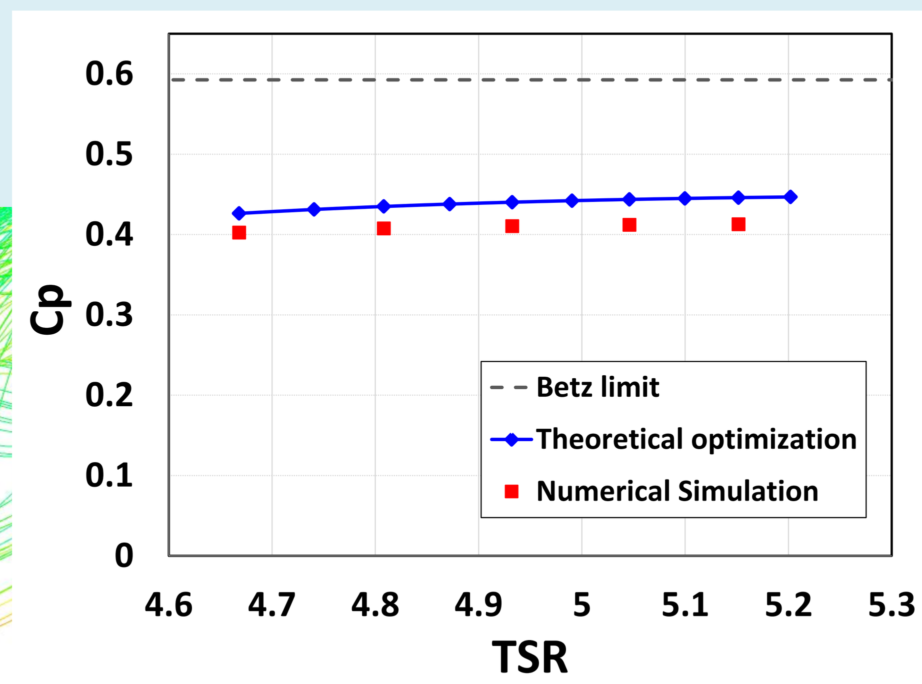
Torque-matched performance of the optimized HAWT rotor

1. The maximum power or the design region, which is near and around the design point.
2. The stall region at low TSR (ωR /v) range causes a dramatically drop in the power.
3. The low α region which appear at high TSR range causes a slightly reduction of the power with increasing TSR.

Numerical simulation

CFD code :Star-CCM+
Domains :Rotating Inner (wind turbine and the near-surrounding air)
Stationary outer (ambient air around the wind turbine)
Interface model :Frozen rotor
Mesh type :Polyhedral
Turbulence model :Spalart-Allmaras
Number of elements :7 million





Validation of theoretical optimized turbine with simulation

The simulations validates the design and optimization method with a slight underestimation, because the losses of the hub and the blades roots (connection with the hub) are not considered in the design and optimization procedure.

Conclusions

- The combination of Schmitz and BEM theories for an initial design and performance analysis of HAWT has advantages of getting new profile that includes the rotational wake. In addition, the exerted forces, torque and power can be calculated with low computational cost, which makes the developed analysis method convenient for optimization cycles.
- The gradient based shape optimization improves the HAWT performance while matching the torque of the rotor to that of the generator over a range of incoming wind velocity and rotational speed.
- Including the profile and tip losses in the optimization procedure made the result more realistic. In general the losses shift the Cp curves to the left due to the reduction of the rotation speed for the same incoming wind velocity.
- The study showed that the torque matching is essential for variable incoming wind velocity and especially for wind turbines employing direct-drive technology in which the rotor is directly coupled to the generator instead of using gearbox to adjust the torque and rotational speed.
- The HAWT performance derived from the theoretical optimization procedure can be well predicted by numerical simulations given that the wall regions are well resolved and the mesh is appropriately distributed away from the walls.