Aeroelastic modelling of vertical axis wind turbines

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Publication date:
2013

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Citation (APA):
Aeroelastic modelling of vertical axis wind turbines

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Renewed interest in Vertical Axis Wind Turbines
- Most floating MW concepts

DeepWind
5MW design

Figure 30. Offshore vertical Aerogenerator concept. Photo: Grimshaw Architects.
Small on-shore Vertical Axis Wind Turbines

Windpower tree

http://www.windpower tree.com/products.htm l

Quiet revolution

http://windpowerdirectory.net/manufacturers/vaw t/quiet-revolution-s14.html

Accurate aerodynamic and aeroelastic design tools are necessary for the design studies of new VAWT concepts

Aeroelastic code HAWC2
– Horizontal Axis Wind Turbine Code
HAWC2 – developed from 2003-2006 at DTU Wind (former Risø)

HAWC2

- Structural core based on a multibody formulation
- Joints modeled by geometric constraints

Use for VAWT’s?

- Arbitrary geometry ✓
- Hydrodynamic loads ✓
- Wave loads ✓
- Mooring lines ✓
- Turbulent inflow model ✓
- Aerodynamic blade loads ✓
- Dynamic stall ✓

- BEM induction model ÷
- Magnus forces on floater ÷
Induction model implemented
The Actuator Cylinder (AC) flow model

- an extension of the actuator disc AD concept to an actuator cylinder

Swept surface a cylinder

Blade forces distributed on the cylinder surface
The AC flow model – the loading

Blade forces distributed on the cylinder surface:

\[ Q_n(\theta) = B \frac{F_n(\theta)\cos(\varphi) - F_t(\theta)\sin(\varphi)}{2\pi R \rho V_{\infty}^2} \]

\[ Q_t(\theta) = -B \frac{F_t(\theta)\cos(\varphi) + F_n(\varphi)\cos(\varphi)}{2\pi R \rho V_{\infty}^2} \]

Where \( F_n(\theta) \) and \( F_t(\theta) \) are the projections of the lift and drag blade forces on a direction normal to chord and tangential to the chord.
How to compute the flow field for the AC model?
1) A standard CFD code can be used:

\[ Q_n(\theta) = \int_{-\Delta s}^{\Delta s} f_n(\theta) dr \]

\[ Q_t(\theta) = \int_{-\Delta s}^{\Delta s} f_t(\theta) dr \]

2) A solution procedure with potentials for low computational demands:

**Approach**: Solution is split into a linear and a non-linear part.

Velocity components are written as:

\[ \nu_x = 1 + w_x \quad \text{and} \quad \nu_y = w_y \]

Equations non-dimensionalized with: \( V_x, \rho, R \)
The Linear solution

Assuming the loading is constant within an interval \( \Delta \theta \)

\[
\begin{align*}
w_x(j) &= \frac{1}{2\pi} \sum_{i=1}^{i=N} Q_{n,i} R_{w_x}(i,j) - Q_{n,j}^* + Q_{n,(N-j)}^* \\
w_y(j) &= \frac{1}{2\pi} \sum_{i=1}^{i=N} Q_{n,i} R_{w_y}(i,j)
\end{align*}
\]

The influence coefficients can be computed once for all:

\[
\begin{align*}
R_{w_x}(i, j) &= \int_{\theta_i-\frac{1}{2}\Delta \theta}^{\theta_i+\frac{1}{2}\Delta \theta} \frac{-(x(j)+\sin(\theta))\sin(\theta) + (y(j)-\cos(\theta))\cos(\theta)}{(x(j)+\sin(\theta))^2 + (y(j)-\cos(\theta))^2} d\theta \\
R_{w_y}(i, j) &= \int_{\theta_i-\frac{1}{2}\Delta \theta}^{\theta_i+\frac{1}{2}\Delta \theta} \frac{-(x(j)+\sin(\theta))\cos(\theta) - (y(j)-\cos(\theta))\sin(\theta)}{(x(j)+\sin(\theta))^2 + (y(j)-\cos(\theta))^2} d\theta
\end{align*}
\]

\[
\begin{align*}
x(j) &= -\cos(j\Delta \varphi - \frac{1}{2}\Delta \varphi) \quad j = 1, 2, ..., 36 \\
y(j) &= \sin(j\Delta \varphi - \frac{1}{2}\Delta \varphi) \quad j = 1, 2, ..., 36
\end{align*}
\]
Results

Solidity \( \sigma = \frac{Bc}{2R} \)
Results – flow

VAWT TEST CASE -- SOLIDITY 0.10

Non-dimensional velocity vs. azimuth position for different models:
- LIN MODEL - LAMBDA 2
- FULL MODEL - LAMBDA 2
- LIN MODEL - LAMBDA 4
- FULL MODEL - LAMBDA 4

FLOW DEFORMATION vs. azimuth position for different models:
- LIN MODEL - LAMBDA 2
- FULL MODEL - LAMBDA 2
- LIN MODEL - LAMBDA 4
- FULL MODEL - LAMBDA 4
A modified linear AC model

The same method of solution (linear and non-linear part) is used for the 2D actuator disc:

\[ v_x = 1 - \frac{\Delta p}{2\pi} \left( \arctg \left( \frac{1-y}{x} \right) + \arctg \left( \frac{1+y}{x} \right) \right) - \Delta p^* \]

\[ v_y = \frac{\Delta p}{4\pi} \ln \left( \frac{x^2 + (y+1)^2}{x^2 + (y-1)^2} \right) \]

\[ C_T = 4a_{\text{lin}} \]

However, from BEM theory we have:

\[ C_T = 4a - 4a^2 \]

To achieve a modified linear solution we multiply the inductions with the factor

\[ k_a = \frac{1}{1 - a} \]
Results – modified linear AC model

![Graph 1: VAWT TEST CASE -- SOLIDITY 0.10 -- AC flow model](image1)

![Graph 2: VAWT TEST CASE -- SOLIDITY 0.10 -- LAMBDA 4](image2)
Results – modified linear AC model
Results

- 5MW DeepWind 2nd design

  rotor radius       60.51m
  blade chord        5.0m
  rotor height       143.0m
  airfoil            NACA0018
  number of blades   2
  solidity           0.17
  rated power        5000kW
  rated speed        5.63rpm
  swept area         12318m2

Baseline design
Results – from baseline to 2nd design
Results

-5MW baseline DeepWind design

![Graph showing DeepWind baseline rotor results at 8m/s with TI=15%](image)
Results

-5MW baseline DeepWind design
Conclusions

- The aeroelastic model HAWC2 has been extended to model VAWT’s with the same level of accuracy as HAWT’s

- Experience on aeroelastic modelling of VAWT’s is being build up at the moment
Acknowledgement

The DeepWind project is supported by the European Commission, Grant 256769 FP7 Energy 2010- Future emerging technologies:

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DTU Wind (DK)
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MARINTEK(N)
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NREL(USA)
STATOIL(N)
VESTAS(DK)
NENUPHAR(F)
Thank you for your attention