

Design of Wind Energy Systems – Summer Term 2015 Tutorial 2: Blade Element Momentum Theory

Davide Trabucchi MSc, Juan José Trujillo MSc

Name:		
Surname:		
Student Nr.		
Email:		
Date of issue:	05.05.2015	Group Nr.
Submission deadline:	12.05.2014	

Exercise 1

During the second tutorial some iteration of the blade element momentum (BEM) algorithm has been run for the rotor in Table 1 at the undisturbed inflow wind speed v_1 of 10 m/s considering ten uniformly distributed annular rings. In this exercise we consider the same specification with a different design of the rotor (see Table 1 and Table 3). Mainly, the design parameters are chosen to increase the contribute of the lift without seeking for an optimal gliding factor.

Table 1 - Turbine design specification

Turbine specification	
Rotor diameter [m]	100
Number of blade [-]	3
Design wind speed [m/s]	10
Design tip-speed-ratio [-]	7
Design lift coefficient* [-]	1.3
Maximal tip-speed [m/s]	70
<hr/>	
Air density [kg/m ³]	1.225

*Based on maximum lift coefficient

1.1 Implement the BEM algorithm and validate it against the results achieved in the class exercise (see Table 3). The following assumption should be considered:

- no wake rotation ($a' = 0$)
- no tip-losses (finite number of blades)
- no drag is produced by the blade elements ($c_D(\alpha_A) = 0$)

- free-stream correction according to Spera (1994)
- linear approximation of the $c_L(\alpha_A)$ curve (see Table 3):

1.2 When the turbine operates in partial load (undisturbed inflow v_1 in the range from 4 to 10 m/s), the rotor and the blades work at the design condition. This means that the pitch and the rotational speed are regulated accordingly. Can you evaluate the overall thrust and aerodynamical power coefficient given at an inflow v_1 of 8 m/s on the basis of the results provided in Exercise 1.1?

Exercise 2

The turbine described in Table 1 and Table 3 reaches its rated power when the wind speed is 10 m/s. In the full load range the design condition are abandoned in order to keep the tip speed below the critical values given by noise limitation and blade abrasion (70-90 m/s) as well as to reduce the structural loads.

2.1 Which operational parameters should be changed in order to comply with the mentioned constraints?

2.2 Evaluate with the BEM solver implemented in Exercise 1.1 which pitch angle is required in order to achieve the rated power at the inflow wind speed v_1 of 14 m/s. Remember that the pitch angle should be added to the design twist of each blade element.

2.3 Calculate for the conditions from point 2.2 the flap moment distribution along the blade and compare the results with those at 10 m/s given in Table 3.

Table 2 - Approximation of lifting coefficient

Note: use this table in case you cannot interpolate conveniently the lift coefficient curve given in the Excel-sheet from CIP-Tutorial.

Angle of attack range	c_L approximation
$-20^\circ \leq \alpha_A < -10^\circ$	$c_L = -0.98 + 0.056 \alpha_A$
$-10^\circ \leq \alpha_A < 0^\circ$	$c_L = 0.2 + 0.062 \alpha_A$
$0^\circ \leq \alpha_A < 15^\circ$	$c_L = 0.2 + 0.095 \alpha_A$
$15^\circ \leq \alpha_A < 22^\circ$	$c_L = 1.6$
$\alpha_A \geq 22^\circ$	$c_L = 2 - 0.02 \alpha_A$

Table 3 – Blade design and results from simplified BEM algorithm at design wind speed (10 m/s) for each blade element.

Position [m]	Chord [m]	Twist [°]	Induction factor [-]	Flap moment [Nm]
2.5	13.59	52.12	0.305	2462227
7.5	8.22	22.23	0.303	2279357
12.5	5.46	10.67	0.297	2011516
17.5	4.03	5.04	0.292	1686641
22.5	3.18	1.77	0.288	1331524
27.5	2.62	-0.36	0.285	972091
32.5	2.22	-1.85	0.283	633704
37.5	1.93	-2.95	0.281	342127
42.5	1.71	-3.79	0.28	122304
47.5	1.53	-4.46	0.278	0

General BEM algorithm including the wake rotation and the free-stream/turbulent wake effect

1 Initialize a and a' to 0	
2 Evaluate the inflow angle α_A	$\alpha = \arctan\left(\frac{V_1(1-a)}{\Omega r(1+a')}\right)$
3 Evaluate the angle of attack of the profile	$\alpha_A = \alpha - (\alpha_{twist} + \alpha_{pitch})$
4 Interpolate the $C_{L,D}$ - α_A curves at the angle of attack α_A	
5 Compute thrust and torque coefficient C_T and C_Q	$C_T = C_L \cos \alpha + C_D \sin \alpha$ $C_Q = C_L \sin \alpha - C_D \cos \alpha$
6 Evaluate a and a'	$a' = \left(\frac{4 \sin \alpha \cos \alpha}{\sigma C_Q} - 1 \right)^{-1}; \quad a = \left(\frac{4 \sin^2 \alpha}{\sigma C_T} + 1 \right)^{-1}$ <p>N: number of blades</p> $\sigma = \frac{N c}{2\pi r}$
7 If $a > a_c$ □ Spera correction	$a = \frac{1}{2} \left(2 + K(1 - 2a_c) - \sqrt{(K(1 - 2a_c) + 2)^2 + 4(Ka_c^2 - 1)} \right)$ <p>where:</p> $K = \frac{4 \sin^2 \alpha}{\sigma C_T}, \quad a_c \approx 0.2$
8 If the difference between the computed induction factors (a, a') and their initialization values is out of tolerance reinitialize a and a' with the newly evaluated values and restart the process from point 2.	