1 CIP 3 - Performance Curves

1.1 Introduction

In this section we analysed the designed turbine under different pitch angles and tip-speed ratios. The design process of a wind turbine differs from turbine to turbine. In order to compare wind turbines non dimensional coefficients are used. These do not depend on factors like size or wind conditions. The most common coefficient is the power coefficient c_p. Further we used the torque coefficient c_q and the thrust coefficient c_t. These coefficient are defined as:

$$c_p = \frac{P}{0.5 * \rho A v^3} \qquad c_t = \frac{T}{0.5\rho A v^2} \qquad c_q = \frac{Q}{0.5\rho A v^2 * R}$$

where:
c_p = Power coefficient
c_t = Thrust coefficient
c_q = Torque coefficient
p = Power
ρ = Density
A = Area
v = Windspeed
R = Rotorradius

1.2 WT_Perf

To compute the nondimensional parameters a program called WT_Perf is used. WT_Perf uses blade-element momentum (BEM) theory to predict the performance of wind turbines. [1]. It also takes different correction algorithms into account, e.g. Prandtl's tip-loss and hub-loss model. WT_Perf can be used from the operating system's command prompt. In order to use WT_Perf we configured the input file by updating the 'Turbine Data' section and implementing the calculated blade geometry. WT_Perf also needs the aerodynamic data of the airfoils. We were able to used the provided data here. Last we defined the range of pitch angle and tip-speed ratio according to the tasks of CIP-3.
The following code-snippet gives an idea of the input file structure:

[1] WT_Perf_Users_guide.pdf

```
------ Turbine Data -----------------------------------------------------------
     3              NumBlade:              Number of blades.
62.18               RotorRad:              Rotor radius.
  1.25              HubRad:                Hub radius.
 -3.0               PreCone:               Precone angle, positive downwind.
  5.0               Tilt:                  Shaft tilt.
  0.0               Yaw:                   Yaw error.
  100               HubHt:                 Hub height.
     8              NumSeg:                Number of blade segments.

  RElm    Twist    Chord   AFfile  PrntElem
 3.808   26.530   6.988      1     FALSE
11.424    9.594   5.407      1     FALSE
19.040    2.661   3.832      1     FALSE
26.656   -0.866   2.906      1     FALSE
34.272   -1.967   2.171      2     FALSE
41.888   -3.354   1.806      2     FALSE
49.504   -4.335   1.544      2     FALSE
57.120   -5.066   1.348      2     FALSE
```

1.3 3.1,3.2

As already mentioned we configured the input file according to CIP-3. The generated output file contains values for the power coefficient c_p, thrust T and torque Q. For task 3.2 we wrote a small python-program which examines the data and plots the results for the three different nondimensional coefficient mentioned in the introduction of CIP-3: c_p, c_t and c_q. Since WT_Perf only writes the power coefficient we had to calculate c_t and c_q. Note that the coefficient are functions of $c_t(\lambda), c_q(\lambda)$. The following figures display the results for c_p, c_t and c_q with a tip-speed ratio λ from one to 20 and pitch angles of : 0,5,10,15,20 and 30 degree. The curves are calculated at rated rotor speed (12.59 rpm).

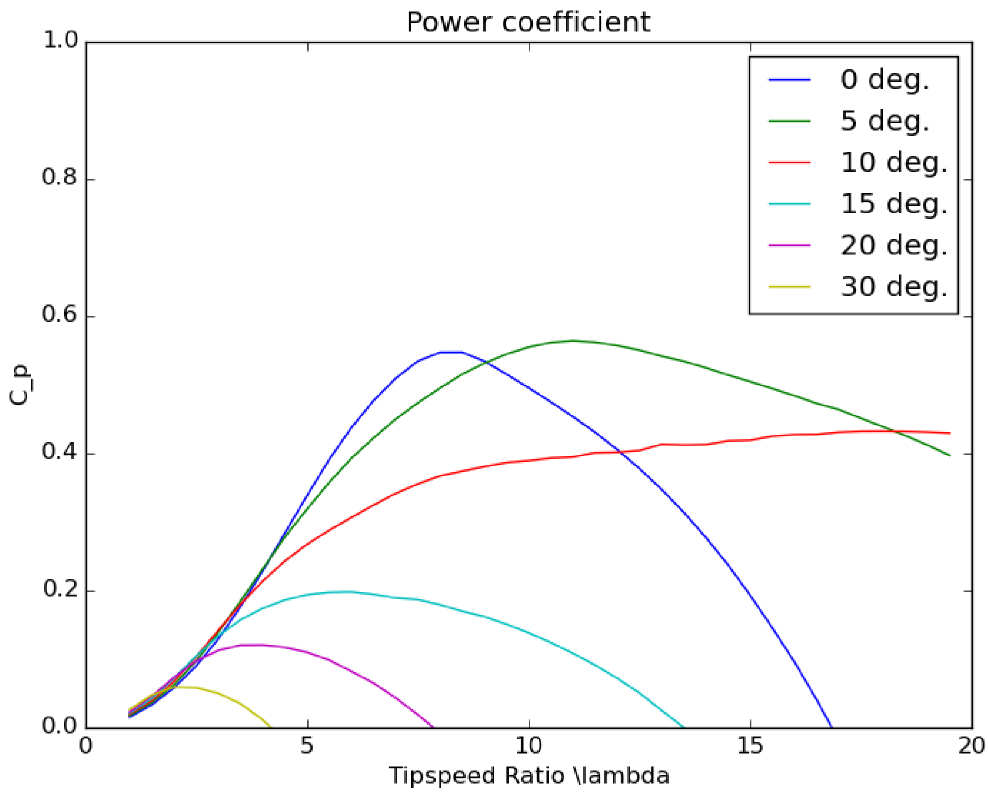

Figure 1: Power coefficient

The $c_p - \lambda$ curve shows different power coefficients at different tip-speeds and pitch-angles. Regarding the maximum for c_p at each curve we identify that they appear at different tip-speed ratios. At pitch angle $5°$ the maximum c_p is at 0.564 which is very close to the theoretical maximum of 0.592.

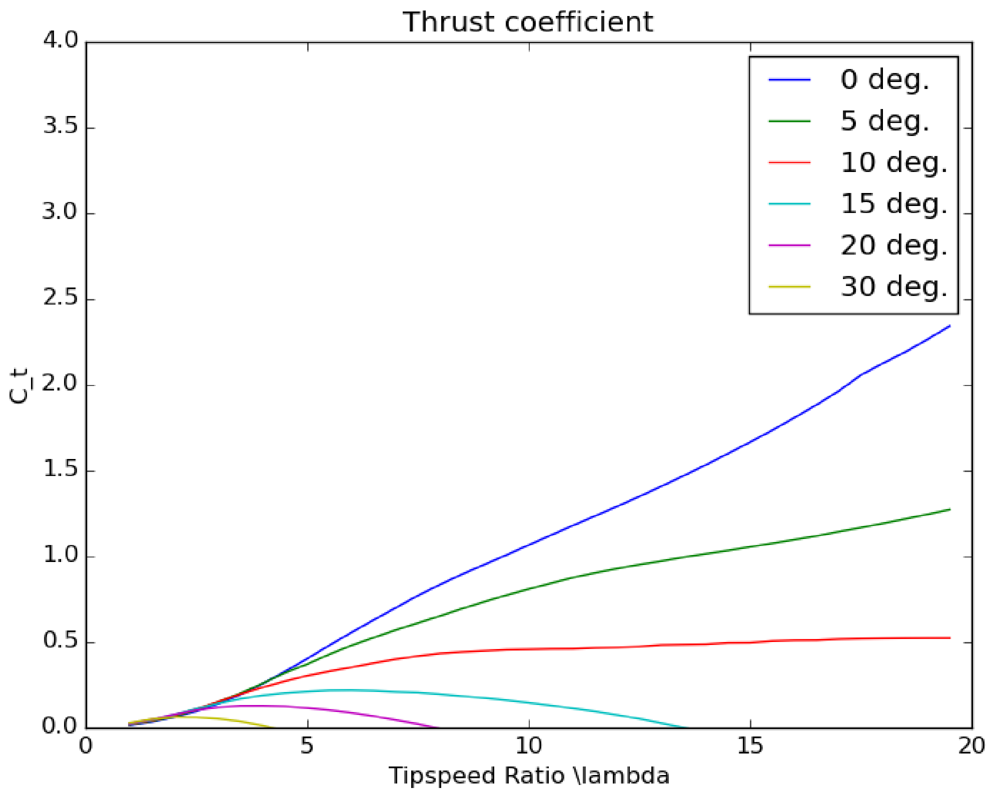

Figure 2: Thrust coefficient

Figure 2 shows the behaviour of the thrust coefficient. From 0° to 10° the thrust coefficient reaches high values. For higher pitch angles the resulting thrust coefficient is significantly lower and is equal to zero for higher tip speed ratios. The thrust is directly applied at the tower and can be decreased by increasing the pitch angle.

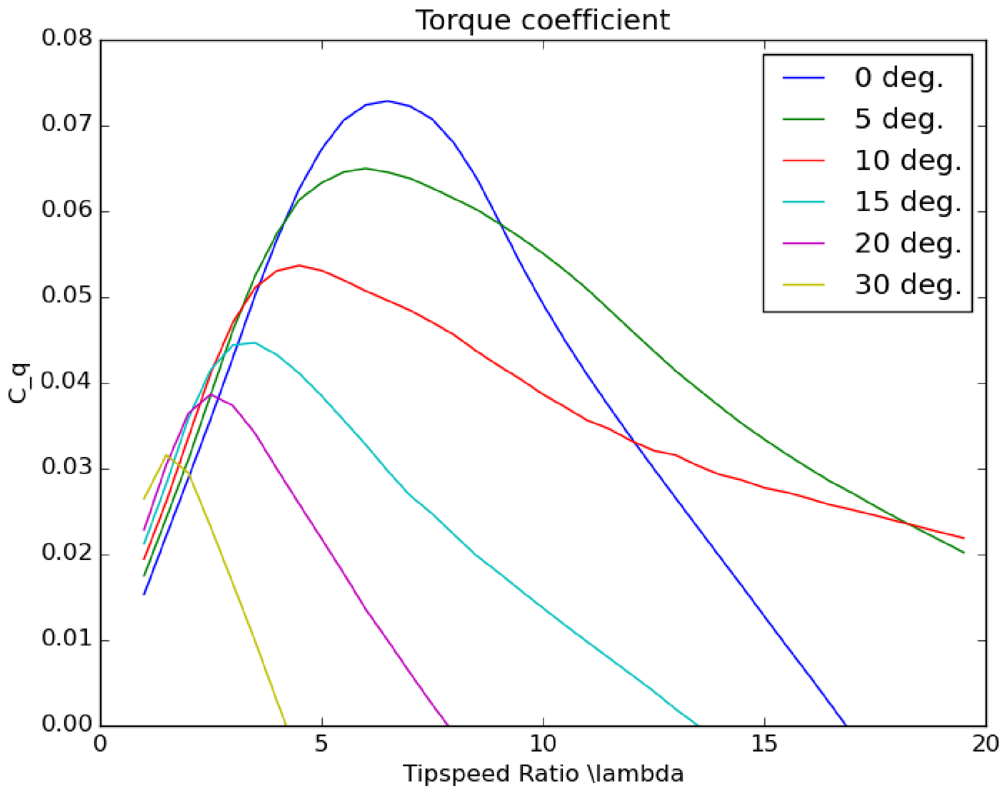

Figure 3: Torque coefficient

Figure 3 shows the torque coefficient for different pitch angles. Compared to the $c_p - \lambda$ the maxima are shifted to the left and decrease with increasing pitch angle.

1.4 3.4

In task 3.4 we were asked to calculate the resulting rotor speed for a rated wind speed of 8 m/s. For the calculation we used our design tip speed ratio:

$$\lambda = \frac{\Omega R}{v} \tag{1}$$

$$n = \frac{60 \lambda v}{2\pi R} = 10.07 rpm \tag{2}$$

1.5 3.5, 3.6

Again we used WT_Perf to calculate the resulting operation conditions below rated wind speed. The input parameters are: v = 8 m/s, design top speed ratio $\lambda = 8.2$ and rotational speed $n =$ 10.07 rpm. The results are shown in the following table:

v	rotor speed	c_p	c_t	c_q	P	
m/s	rpm	-	-	-	kW	Power aus WT_Perf
8	10.07	0.544	0.825	0.033	2054.846	

1.6 3.7,3.8

According to Betz, the wind turbine should be able to extract 7618 kW. However the rated power of the wind turbine is lower than the power which could be extracted. Therefore pitching is needed. The resulting c_p can be calculated as follows:

$$c_p = \frac{3500000}{0.5 \cdot 1.225 \cdot \pi \cdot 62.18^2 \cdot 12^3} = 0.272 \tag{3}$$

1.7 3.9

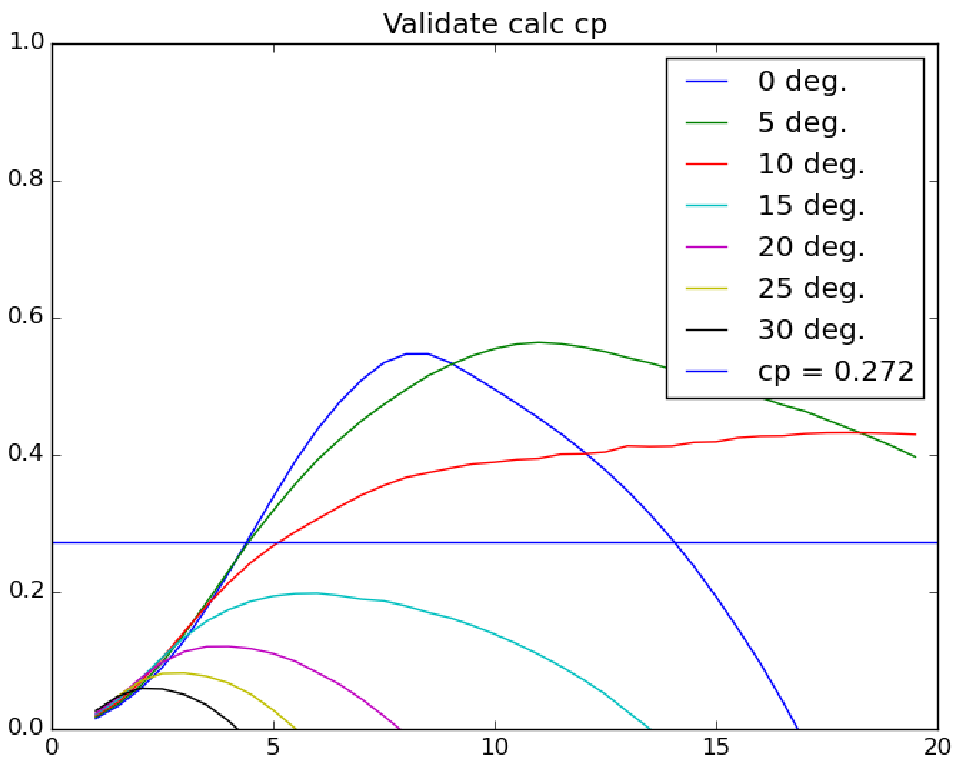

Figure 4: Validation of c_p
The resulting c_p corresponds to a tip speed ratio of 5 with a pitch angle of 10°

1.8 3.10

$$n = \frac{60\lambda v}{2\pi R} = 9.21$$