Computed performance of the 14.3m OlsenWing blade on a 15m radius rotor

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Resume (max. 2000 char.):
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Content

1 Introduction

This report contains computed performance data for the 14.3m OlsenWing blade. The performance is shown as power and thrust as well as the corresponding power and thrust coefficients for the blade mounted at a 3 bladed rotor with tip radius 15.0m. Furthermore, necessary pitch settings and rotational speed to obtain the power are also shown. In the end some load considerations for an extreme event are described.

When reading the report it is important to be aware of the following:

- The data shown is predicted data and not measured. It is believed that the power and thrust predictions are rather accurate at low winds speeds, i.e. when separation does not occur at the blade. The more separation that occur, the higher the uncertainties become. Thus, in general terms, the power and thrust curves below approximately 10m/s are rather trustworthy and becomes more and more uncertain for increasing wind speeds above 10m/s. In Figure 1 and Figure 2 an example of a power curve and a thrust curve for an active stall regulated wind turbine are seen. The grey curves/points shows measured data and the other curves show predicted performance using five different models to correct for 3D effects/centrifugal and Coriolis forces. It is seen that uncertainties up to 20% between predicted and measured data can occur.

- The shown power and thrust curves should be interpreted as mean values. Thus, because of

    - the stochastic character of the wind,
    - changes in wind direction and thereby changes in turbulence intensity and the character of the turbulence,
    - changes in surface conditions on the blade,
    - possible yaw misalignment,
    - possible shut down of the wind turbine

  and much more, it should not be expected that the rotor and wind turbine at all times will perform according to the shown curves. Sometimes e.g. the power will be somewhat lower and sometimes it will be somewhat higher than the predicted curves show. However, when assuming clean blades, zero yaw misalignment, low turbulence and steady wind are assumed, the rotor is expected to perform according to the plots shown in this report, with the uncertainties of the models taken into account as described above. An example of measurements is shown in Figure 2, where each grey point corresponds to a 10 minutes mean value. It is seen that each grey point is not always aligned on a curve. Thus, this illustrates some of the uncertainties that can be expected. It should be noted that much more scatter in the data compared to the figures below can be the case for highly turbulent sites.

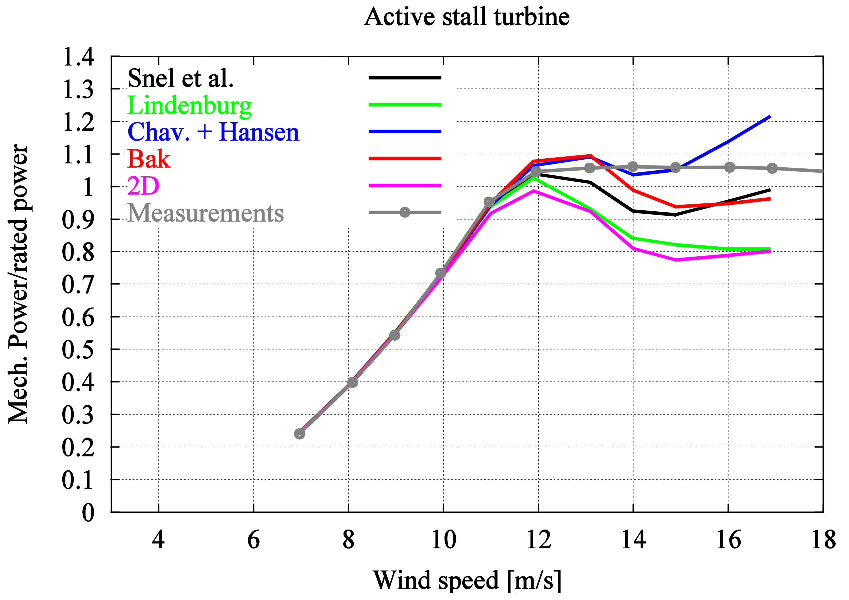

Figure 1 Power curve for an active stall regulated wind turbine. Measurements are compared to computations using five different models that can correct the 3D effects in stall/separated flow. Figure from Bak et al.[iii]

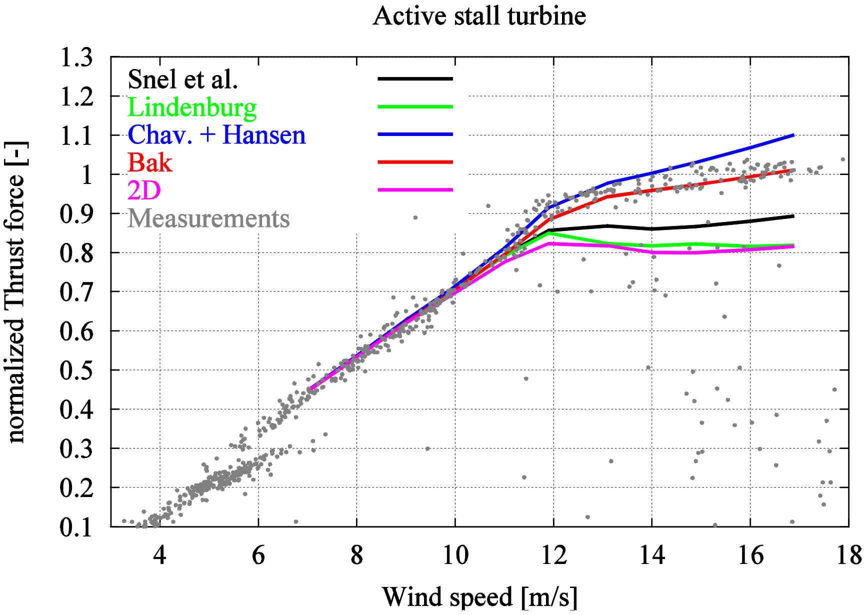

Figure 2 Thrust curve for an active stall regulated wind turbine. Measurements are compared to computations using five different models that can correct the 3D effects in stall/separated flow. Figure from Bak et al.[iii]

2 Blade data

Key parameters for the blade are shown in Table 1.

Table 1 Key parameters for the blade

Parameter	Value
Blade length [m]	14.3
Rotor radius [m]	15.00
Maximum chord length/blade width [m]	1.330
Design tip speed ratio [-]	8
Maximum mechanical power coefficient [-]	0.476
Design tip pitch [°]	0

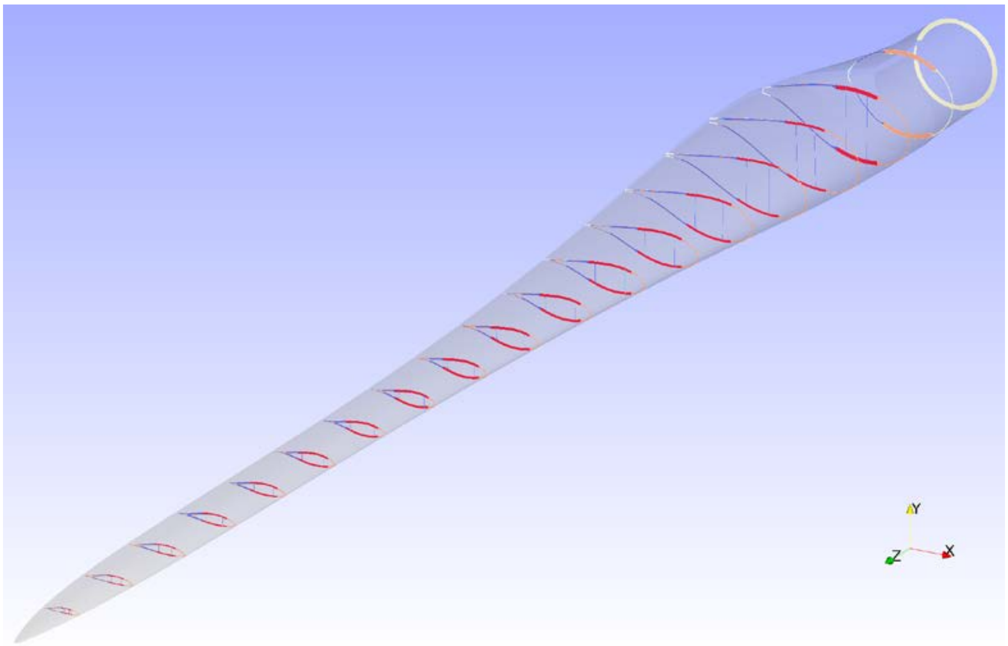

Figure 3 Blade in perspective.

Figure 4 Blade top view.

3 Predicted blade performance

In this chapter the predicted performance for the 14.3m-blade mounted on a hub with 0.70m radius, which in total gives a rotor radius of 15.0m is shown.

3.1 Method

The HAWTOPT code[i] was used to predict the aerodynamic performance. The airfoil characteristics where predicted using *XFOIL*[ii] with a weighting between free transition flow and forced transition flow to take into account unavoidable leading edge roughness and thereby avoid too optimistic predictions. The data was afterwards corrected for 3D effects using the method described by Bak et al[iii]. The validity of this model is indicated in the plots shown in Figure 1 and Figure 2 and also compared to other 3D correction models.

3.2 Overview

To make an overview of the performance, the power coefficient as a function of tip pitch and tip speed ratio is shown in Figure 5.

- *Tip pitch:* The tip pitch is given as the angle between chord line at the tip (the chord line is the line from the very leading edge to the trailing edge at the airfoil) and the rotor plane. Positive pitch angles mean that the leading edge is rotated into the wind, whereas negative pitch angles mean that the leading edge is rotated into the wake of the rotor.
- *Tip speed ratio:* The tip speed ratio is the ratio between the tip speed of the rotor [m/s] and the wind speed [m/s]. The blade is designed to operate optimal at a tip speed ratio at 8. This means that if the wind speed is 5m/s the tip speed at which maximum power is produced is 8*5m/s=40m/s.
- *Power coefficient:* The power coefficient is defined as $CP=P/(0.5*\rho*V^3*A)$, where ρ is the air density [kg/m^3] (ρ=1.225kg/m^3 at 15°C), V is the wind speed [m/s] and A is the rotor area ($A=\pi*R^2$, where R is the rotor radius). In this report only the mechanical power coefficient is shown, i.e. no losses from e.g. generator and gear box are included.

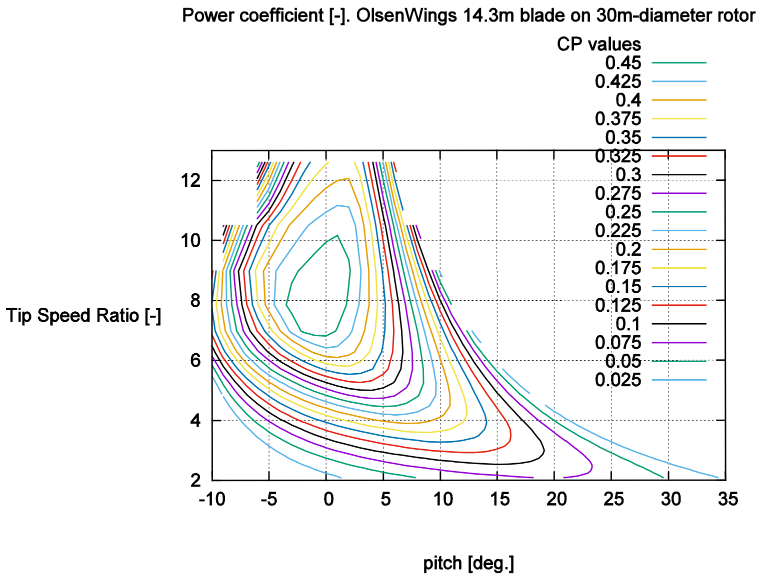

Figure 5 Power coefficient as a function of tip pitch angle and tip speed ratio.

4 Stall regulation

In this chapter several power curves are shown as a function of rotational speed and tip pitch settings. It should be noted as described in the introduction to this report that prediction of the power at high wind speeds (at and greater than approximately 15m/s), where the power is being limited, is uncertain because the separated flow at the blade is highly influenced by centrifugal and Coriolis forces and other 3D effects. Thus, the performance at these wind speeds should be interpreted in the order of these magnitudes. Together with the uncertainty of the tip pitch when installing a blade the power as shown below could be in the order of +/-20%.

4.1 Constant rotational speed at 25RPM

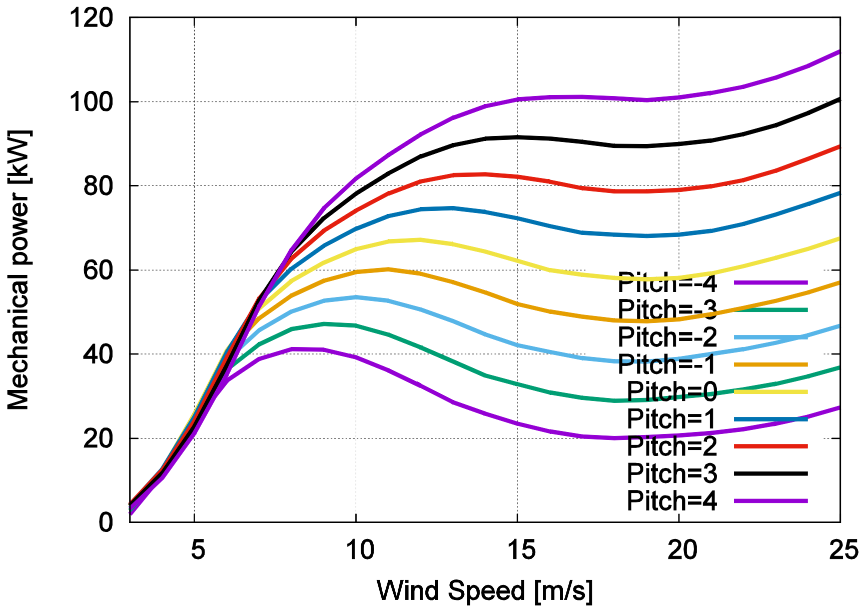

Figure 6 Mechanical power (no loss from generator and gear box) as a function of wind speed.

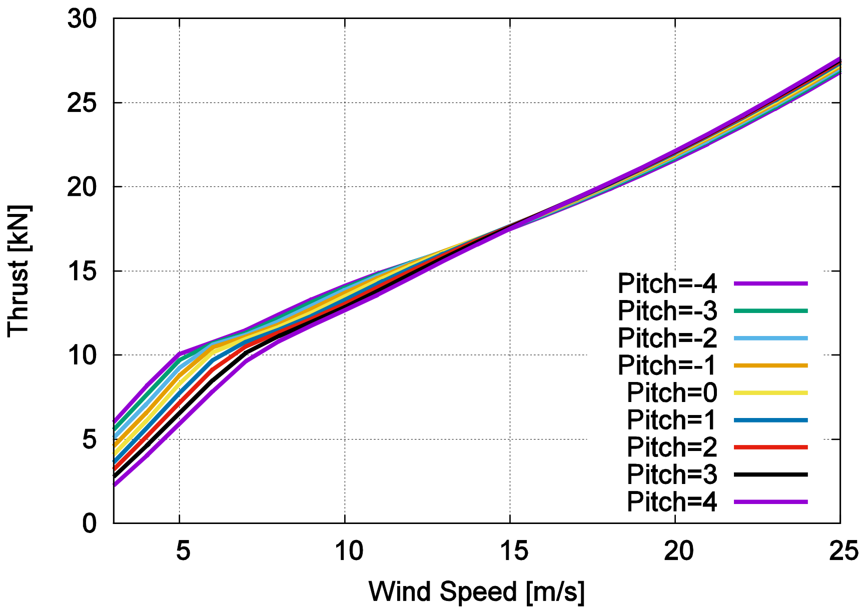

Figure 7 Thrust as a function of wind speed.

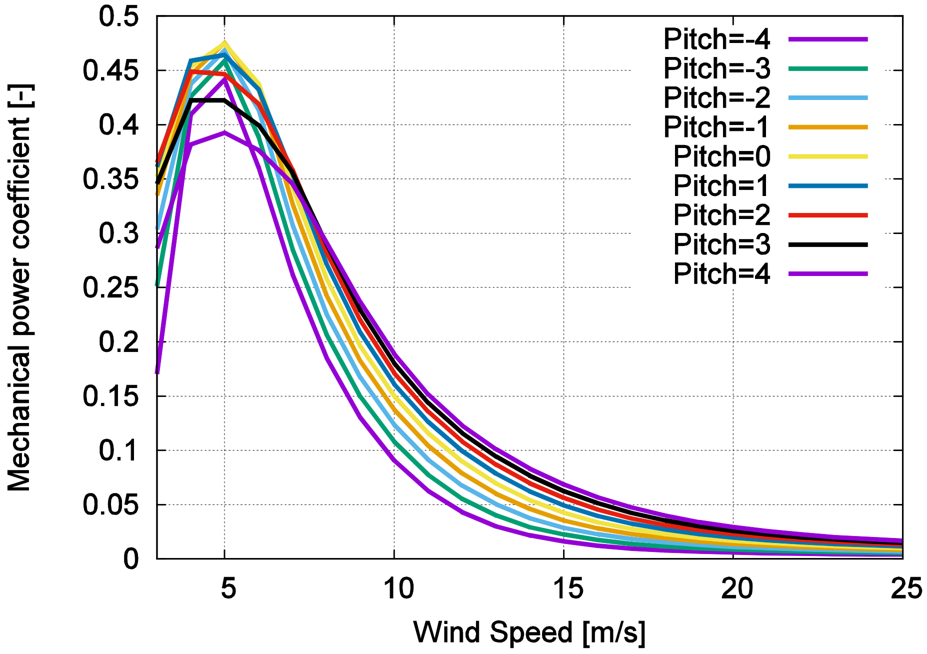

Figure 8 Mechanical power coefficient (no loss from generator and gear box) as a function of wind speed.

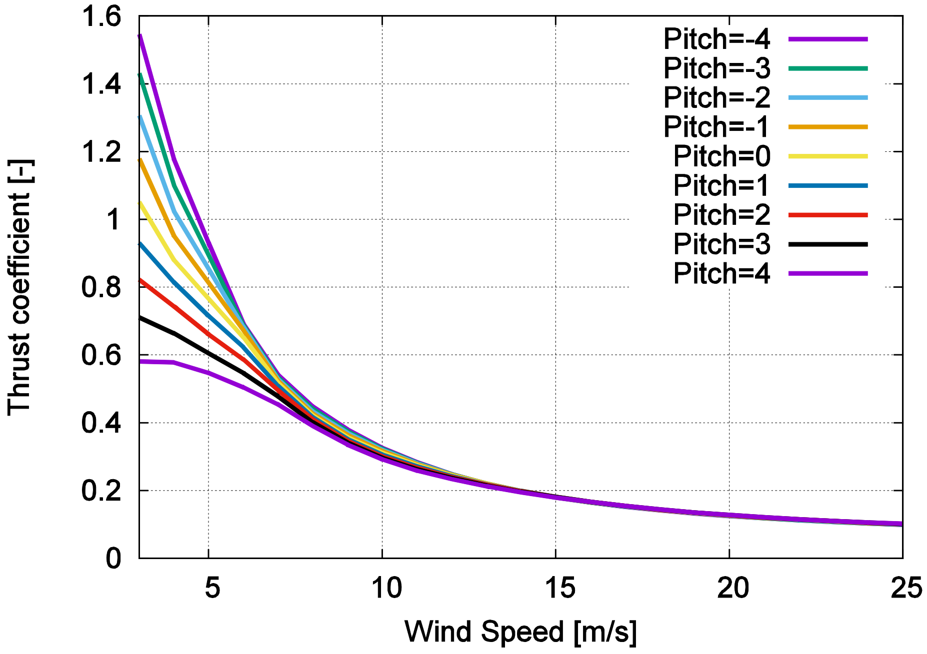

Figure 9 Thrust coefficient as a function of wind speed.

4.2 Constant rotational speed at 30RPM

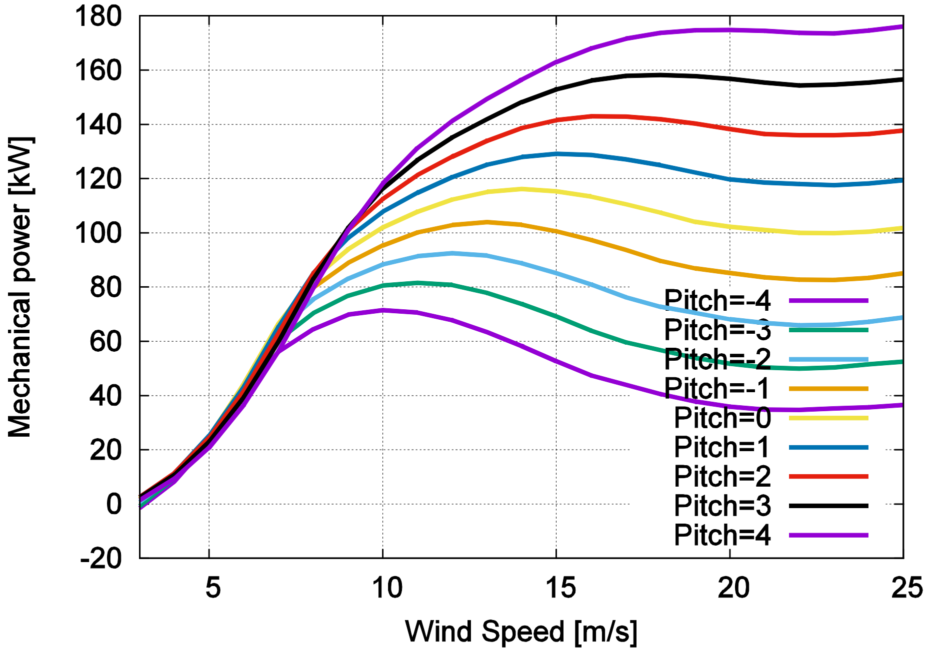

Figure 10 Mechanical power (no loss from generator and gear box) as a function of wind speed.

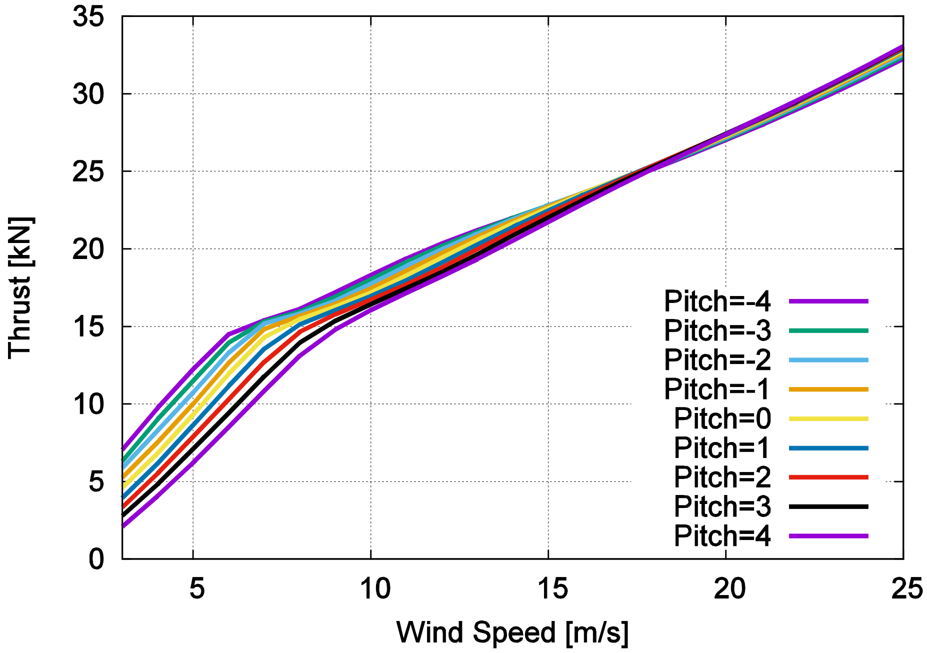

Figure 11 Thrust as a function of wind speed.

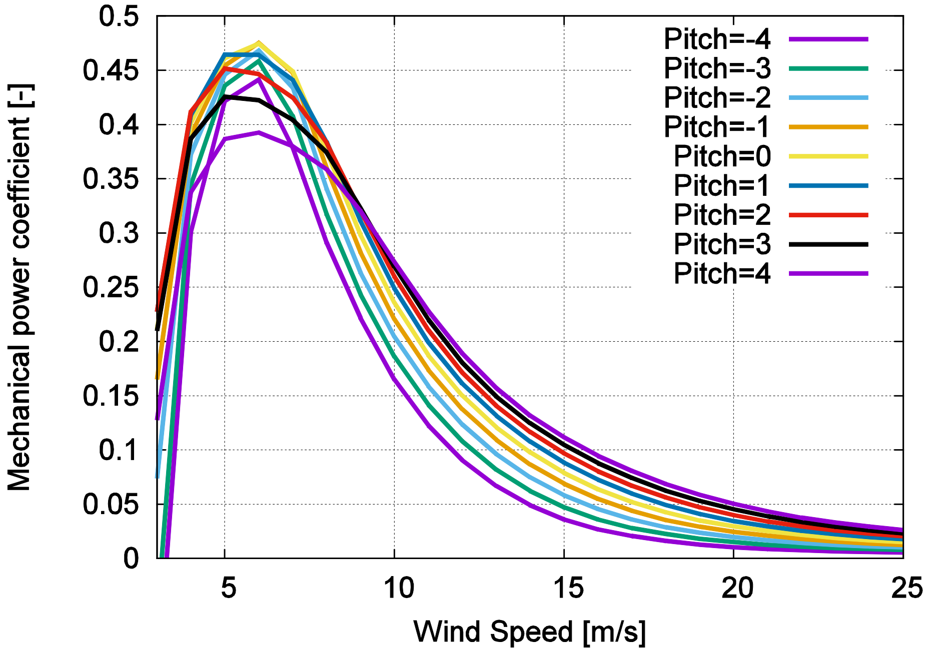

Figure 12 Mechanical power coefficient (no loss from generator and gear box) as a function of wind speed.

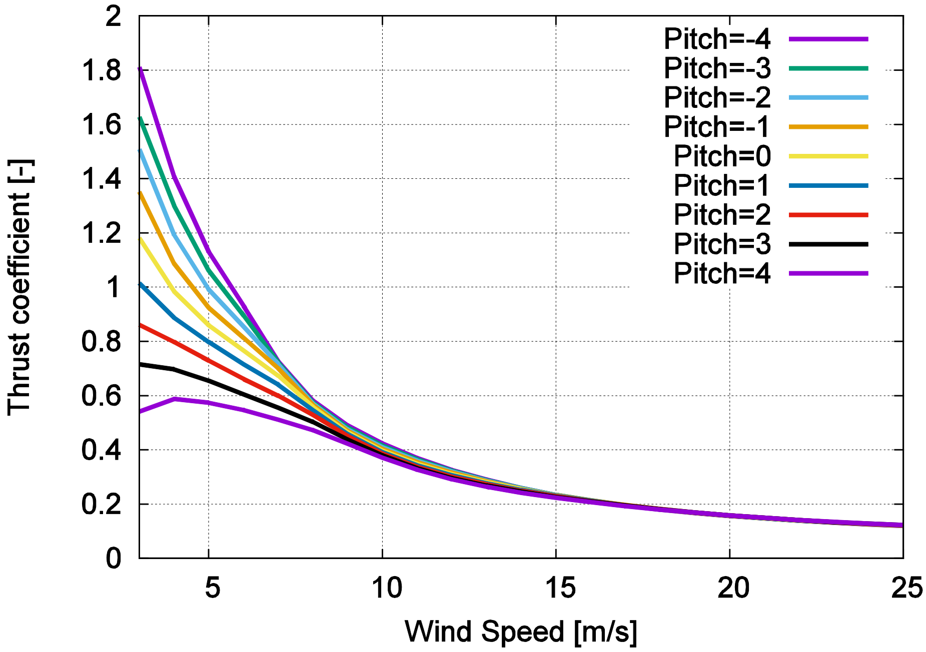

Figure 13 Thrust coefficient as a function of wind speed.

4.3 Constant rotational speed at 35RPM

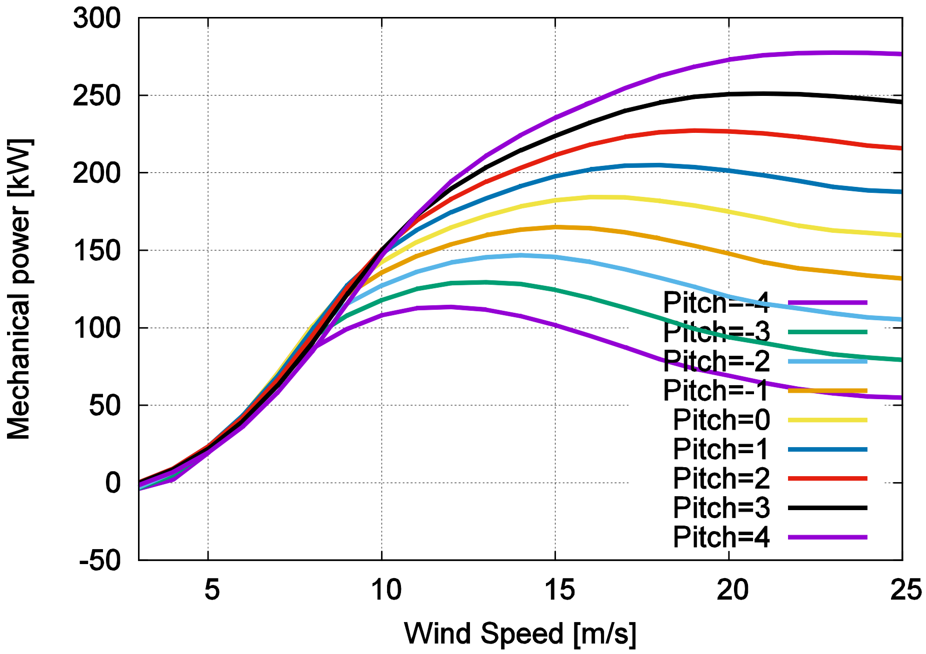

Figure 14 Mechanical power (no loss from generator and gear box) as a function of wind speed.

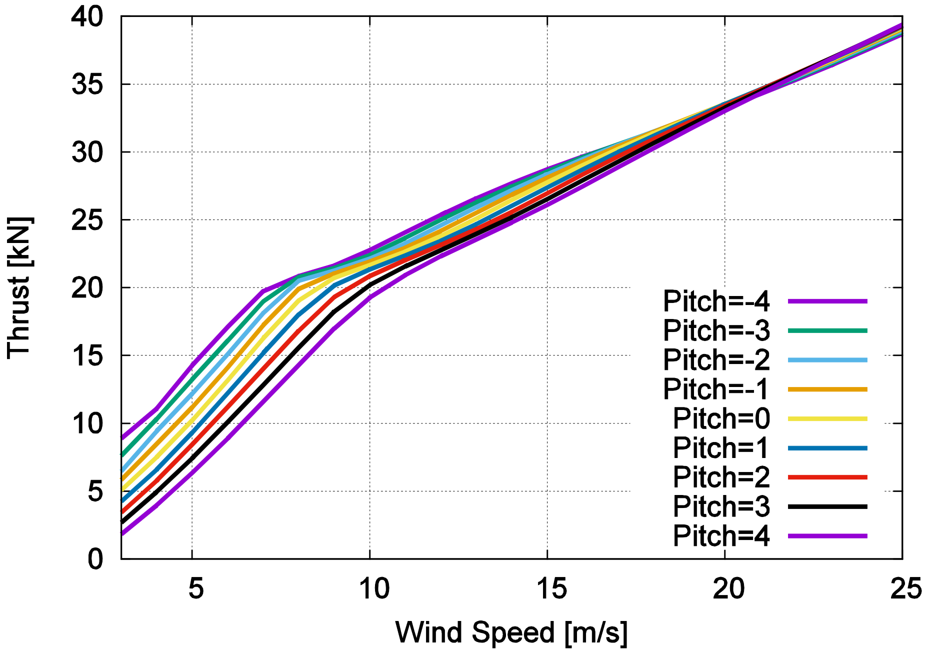

Figure 15 Thrust as a function of wind speed.

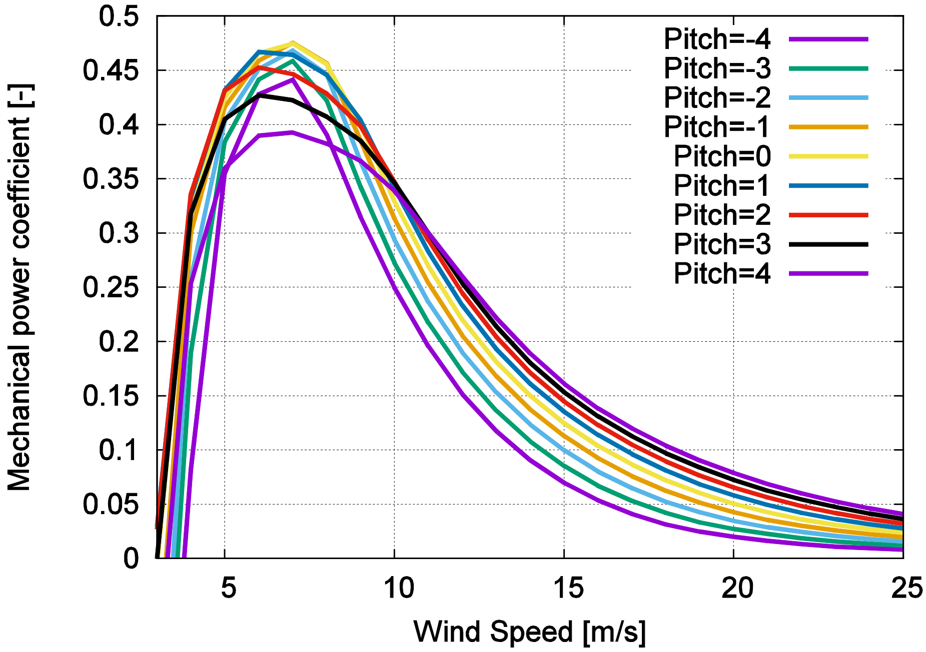

Figure 16 Mechanical power coefficient (no loss from generator and gear box) as a function of wind speed.

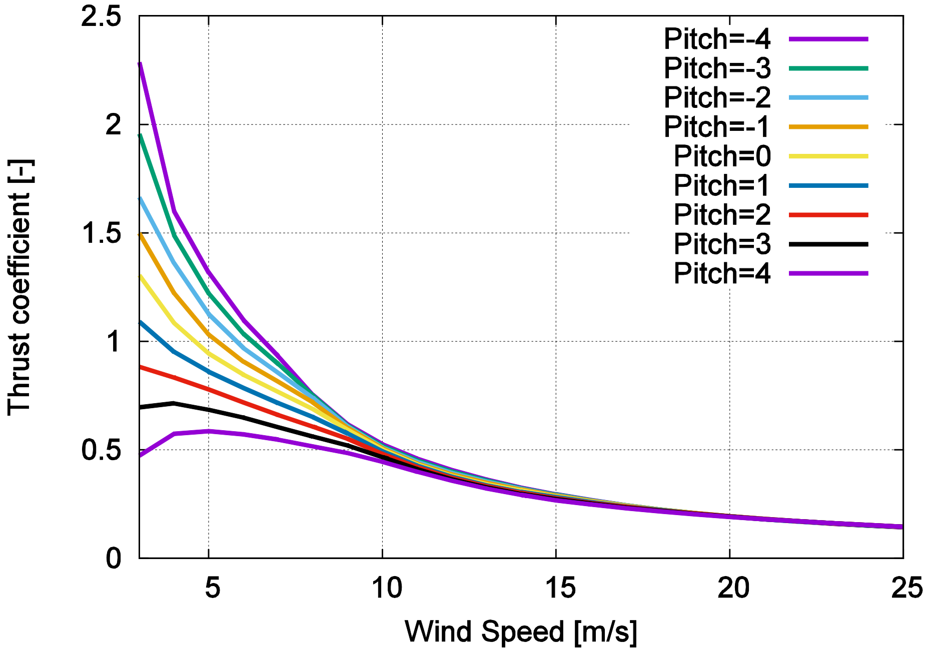

Figure 17 Thrust coefficient as a function of wind speed.

4.4 Constant rotational speed at 40RPM

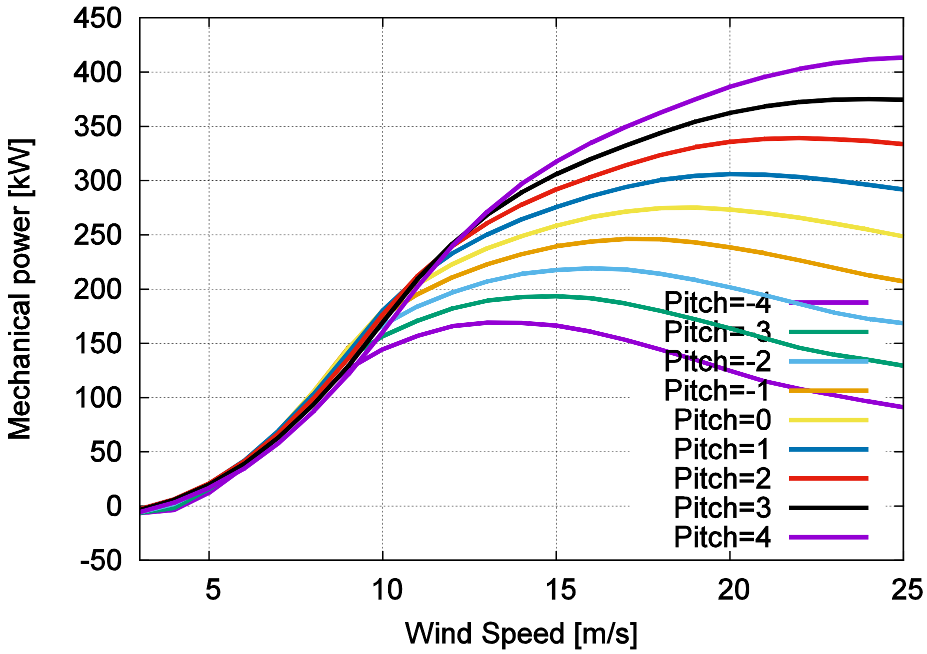

Figure 18 Mechanical power (no loss from generator and gear box) as a function of wind speed.

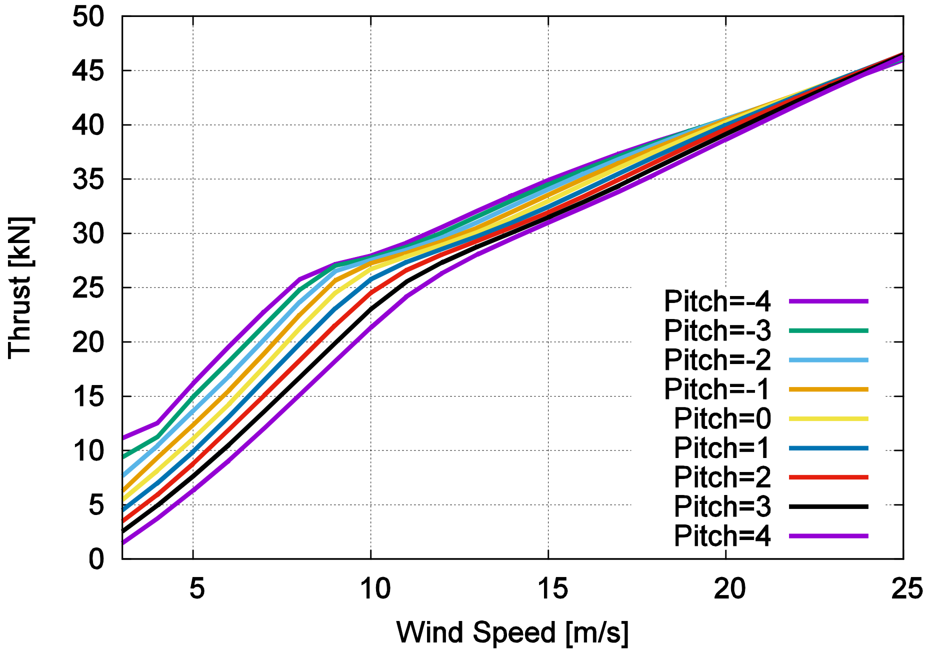

Figure 19 Thrust as a function of wind speed.

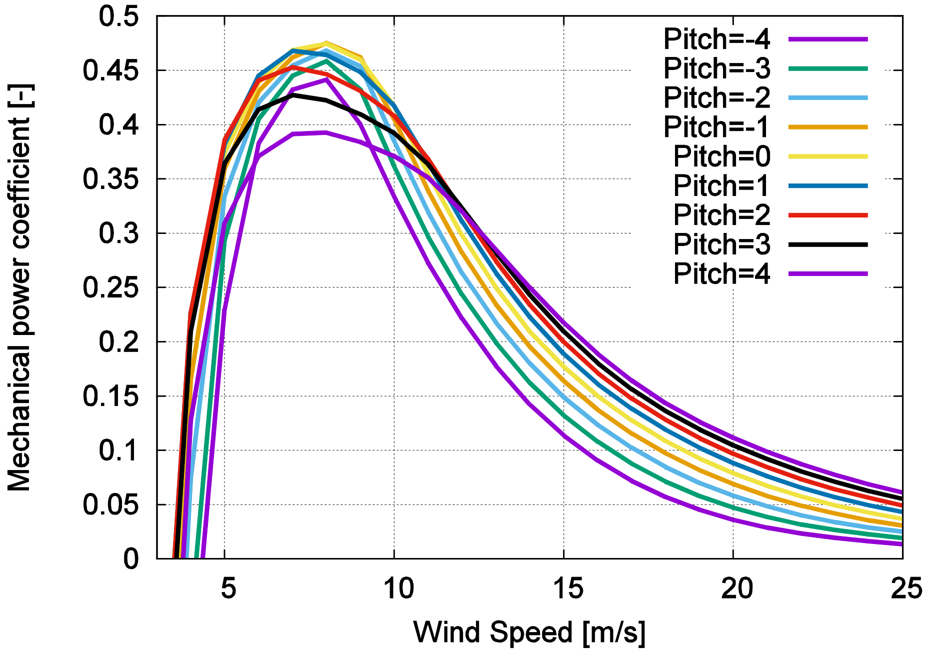

Figure 20 Mechanical power coefficient (no loss from generator and gear box) as a function of wind speed.

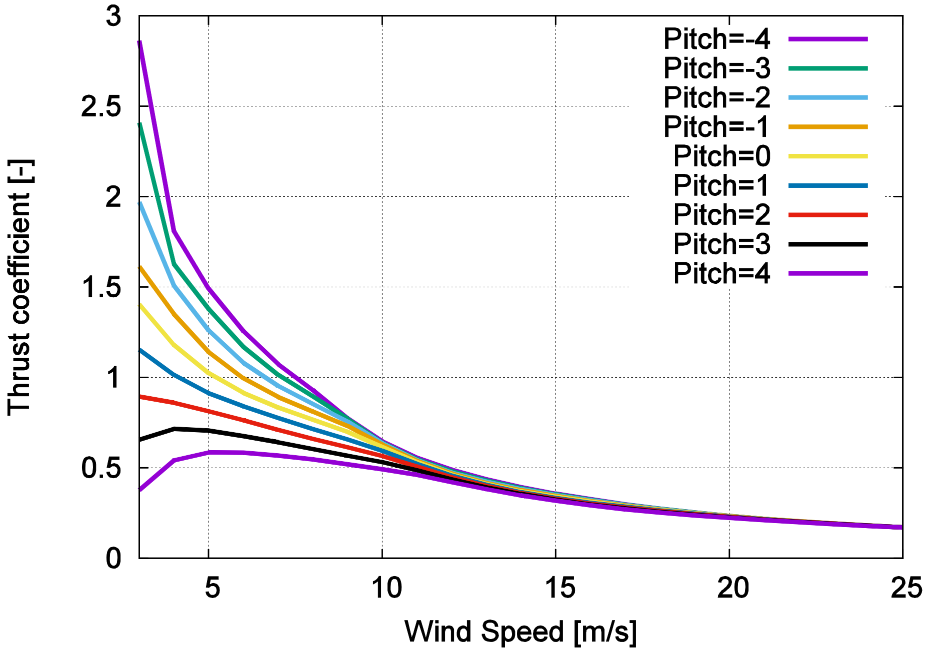

Figure 21 Thrust coefficient as a function of wind speed.

4.5 Constant rotational speed at 45RPM

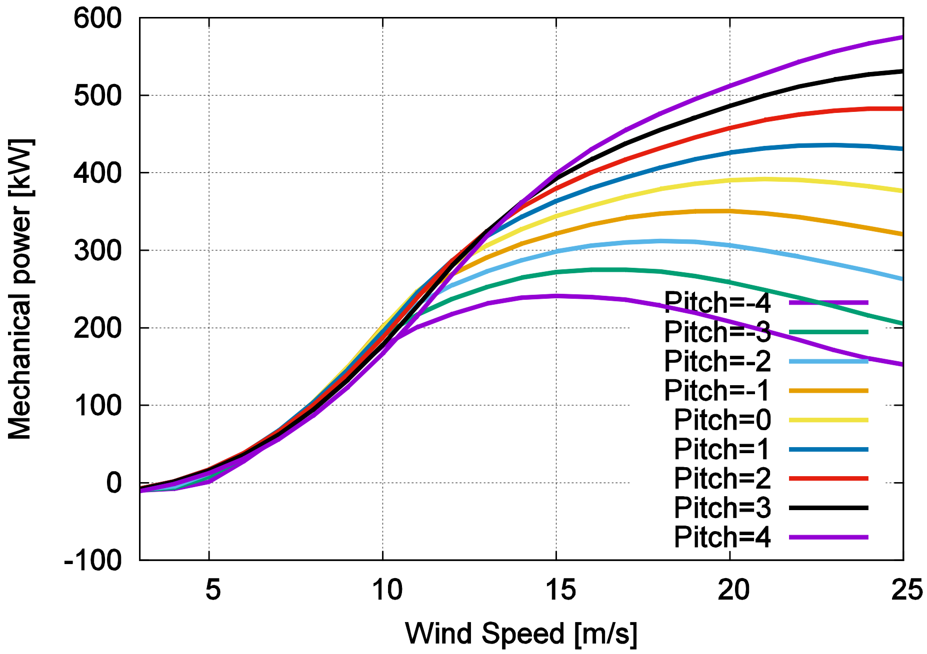

Figure 22 Mechanical power (no loss from generator and gear box) as a function of wind speed.

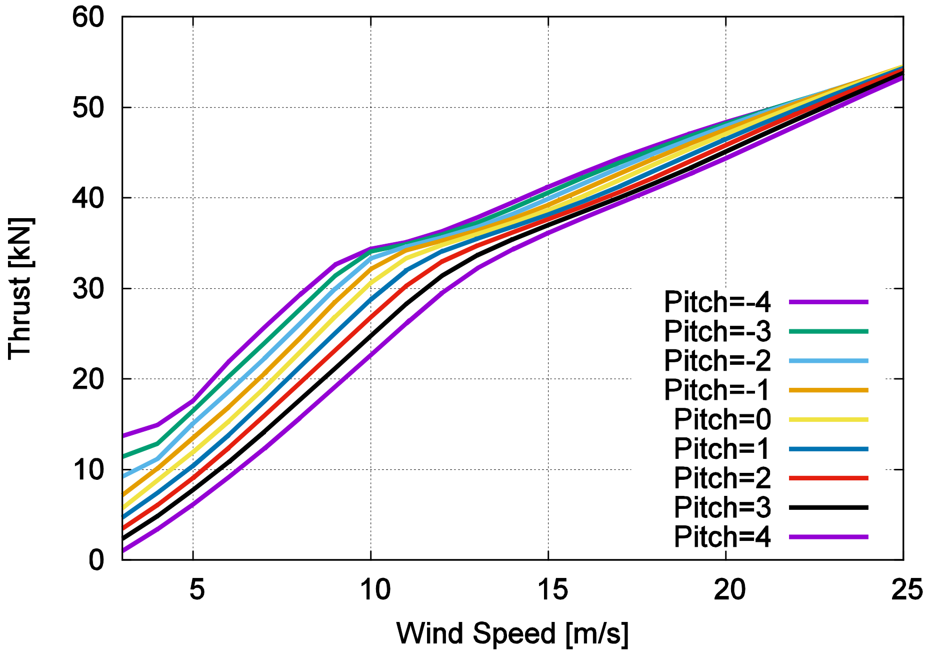

Figure 23 Thrust as a function of wind speed.

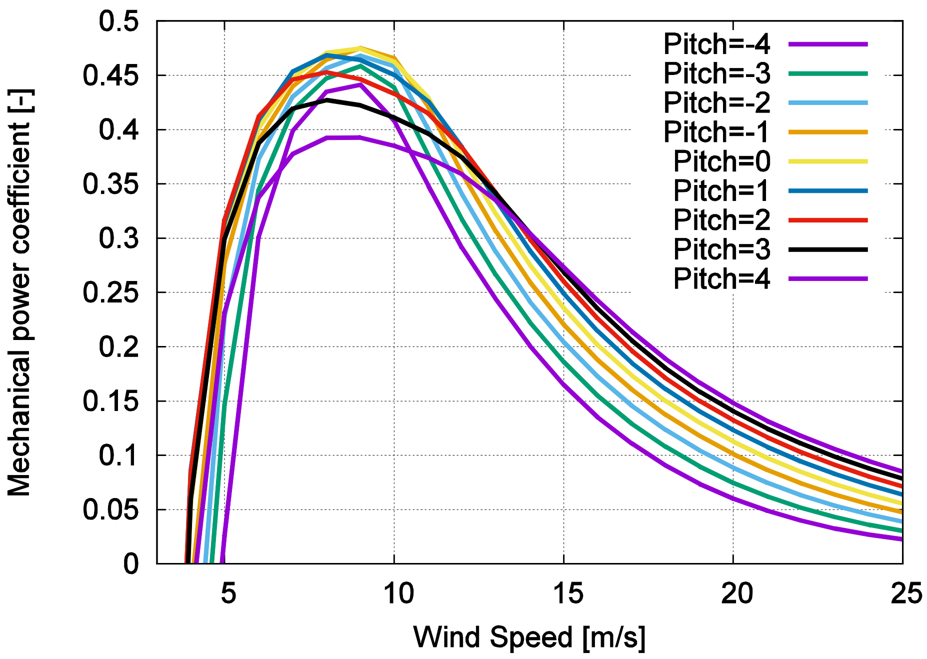

Figure 24 Mechanical power coefficient (no loss from generator and gear box) as a function of wind speed.

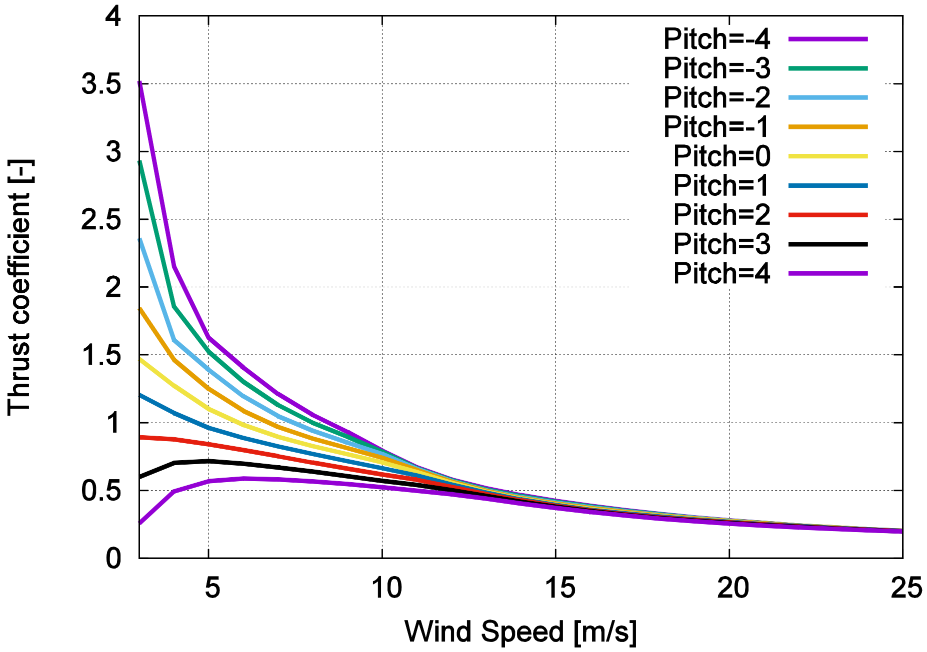

Figure 25 Thrust coefficient as a function of wind speed.

5 Pitch regulation, constant rotational speed

In this chapter the blade used for a pitch regulated turbine is predicted. The pitch values are predicted for constant rotational speed. If a rotor is controlled by pitch regulation and variable rotor speed, the variable rotor speed should be chosen so that the tip speed ratio is (close to) 8 with a tip pitch of 0°. Variable speed control is however not shown below. When the rotor speed has reached its maximum and the power is being limited, the pitch curves as below can be used if the maximum rotor speed is one of the values as shown below.

5.1 Constant rotational speed at 25RPM

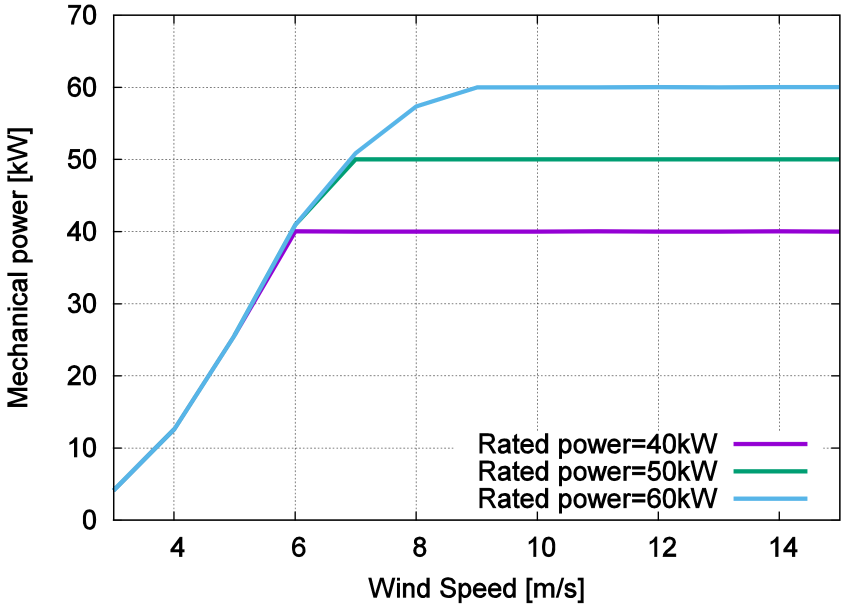

Figure 26 Mechanical power (no loss from generator and gear box) as a function of wind speed.

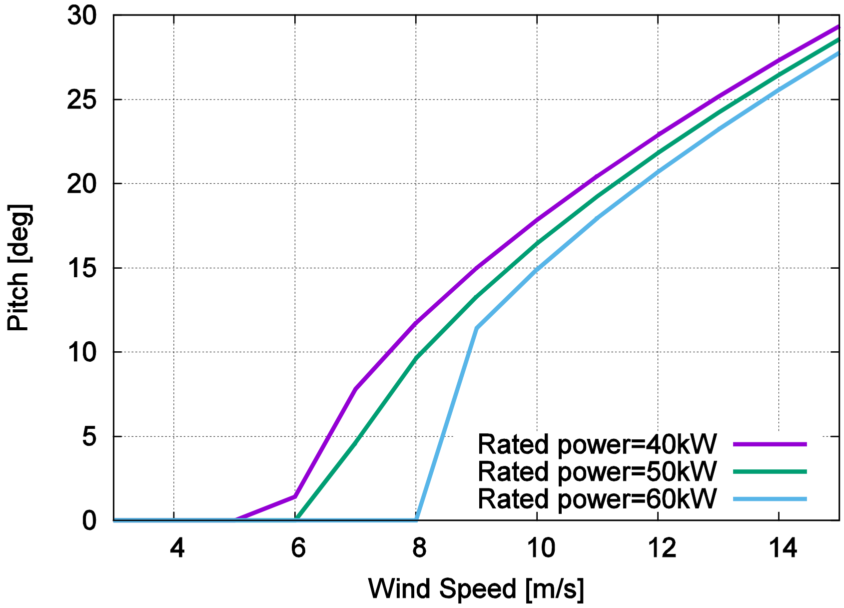

Figure 27 Pitch as a function of wind speed.

5.2 Constant rotational speed at 30RPM

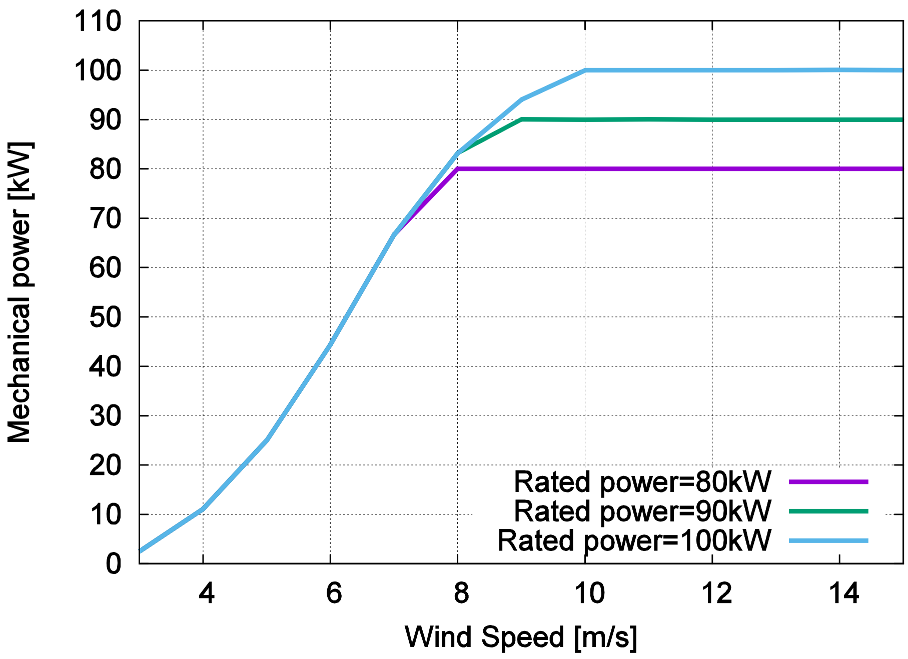

Figure 28 Mechanical power (no loss from generator and gear box) as a function of wind speed.

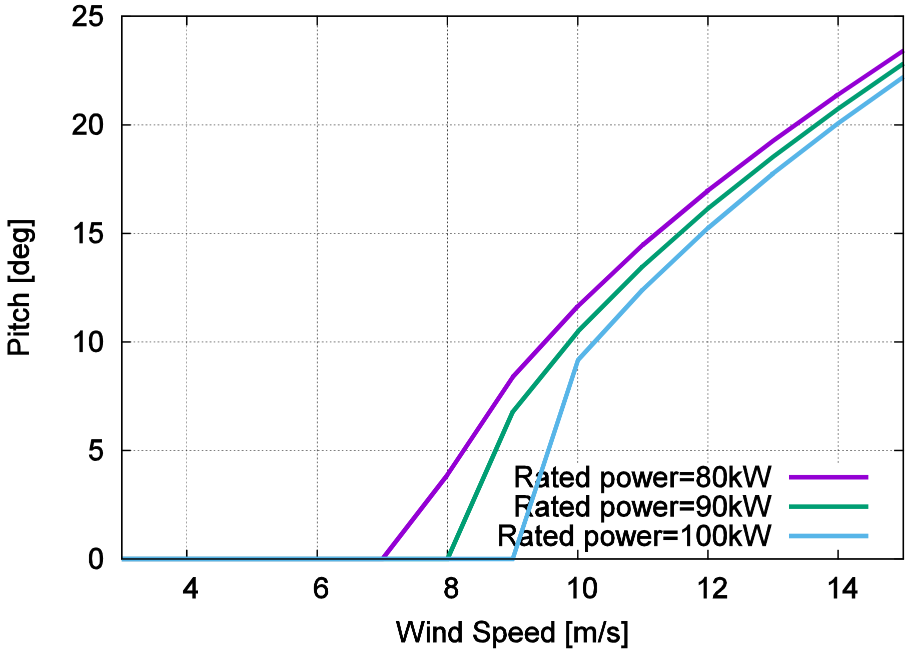

Figure 29 Pitch as a function of wind speed.

5.3 Constant rotational speed at 35RPM

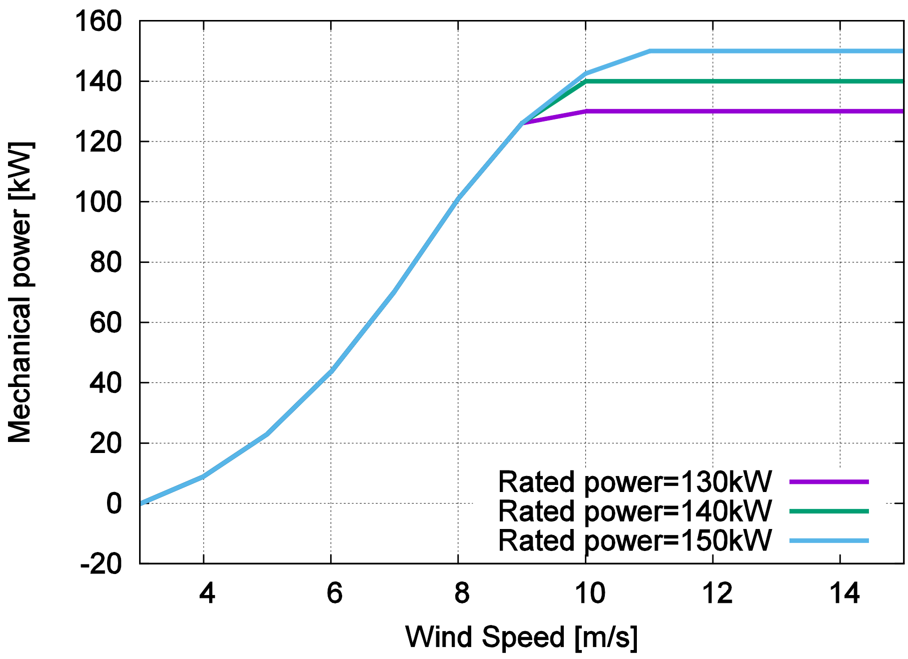

Figure 30 Mechanical power (no loss from generator and gear box) as a function of wind speed.

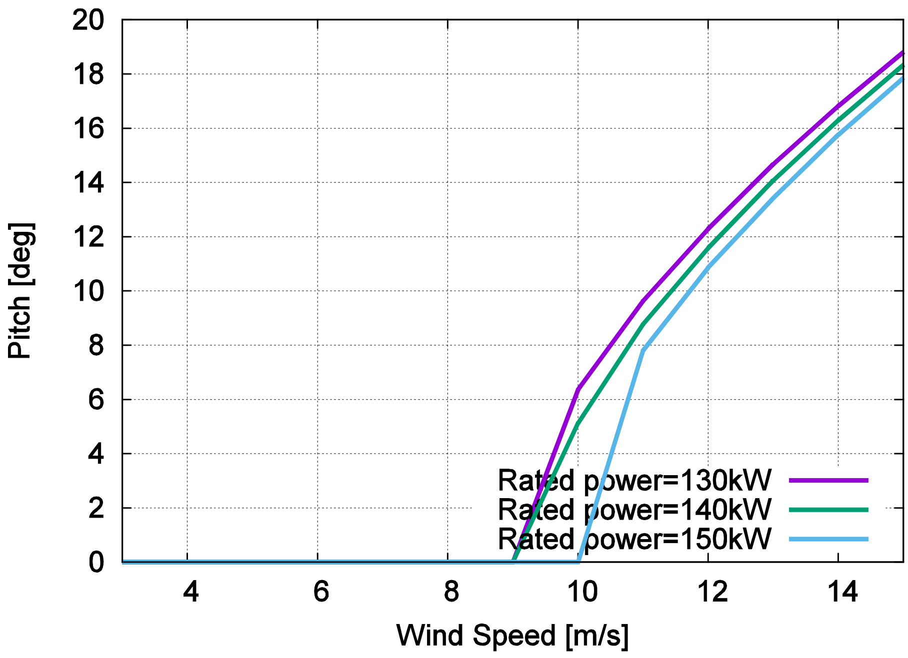

Figure 31 Pitch as a function of wind speed.

5.4 Constant rotational speed at 40RPM

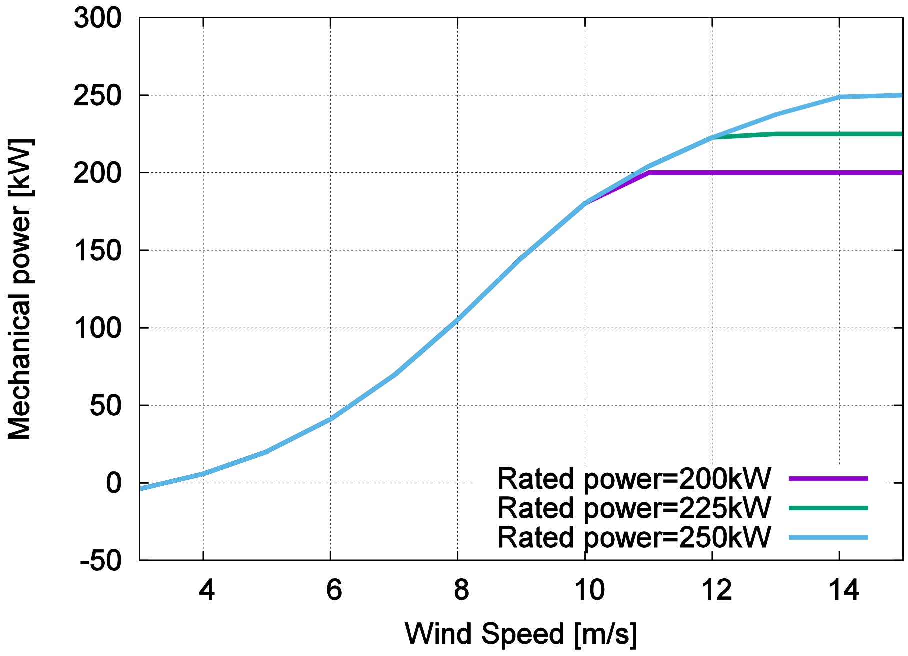

Figure 32 Mechanical power (no loss from generator and gear box) as a function of wind speed.

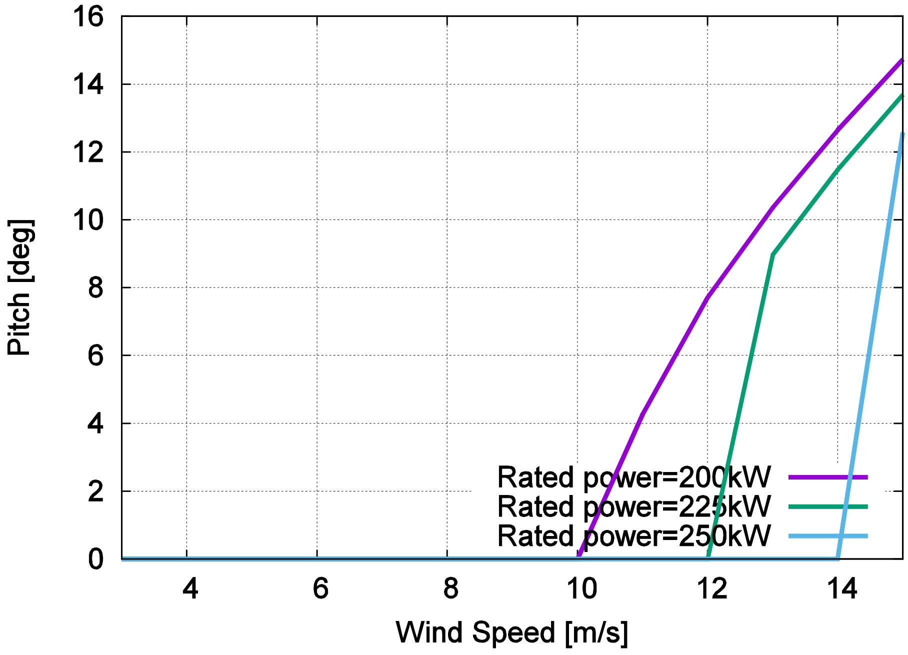

Figure 33 Pitch as a function of wind speed.

5.5 Constant rotational speed at 45RPM

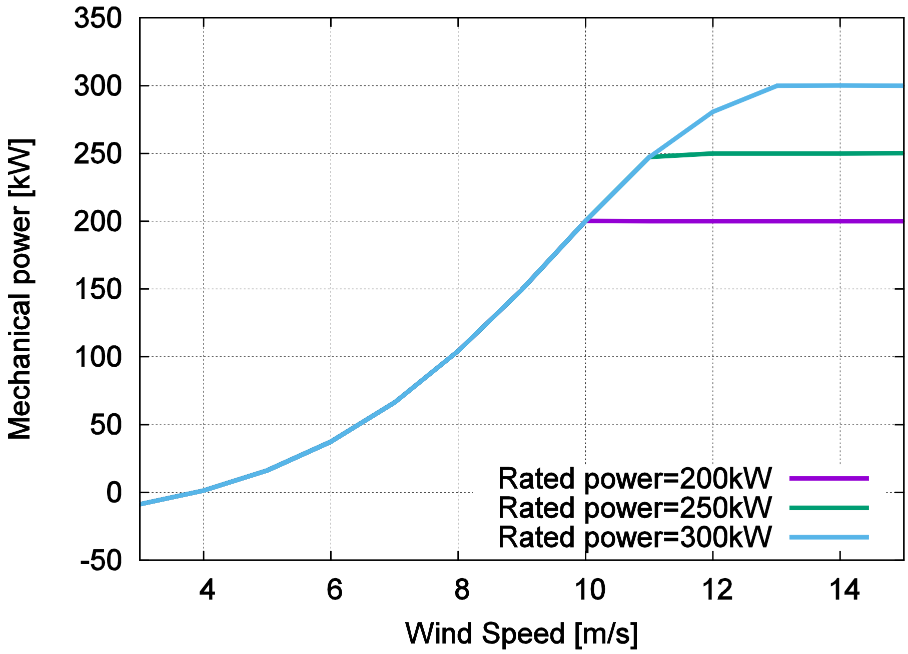

Figure 34 Mechanical power (no loss from generator and gear box) as a function of wind speed.

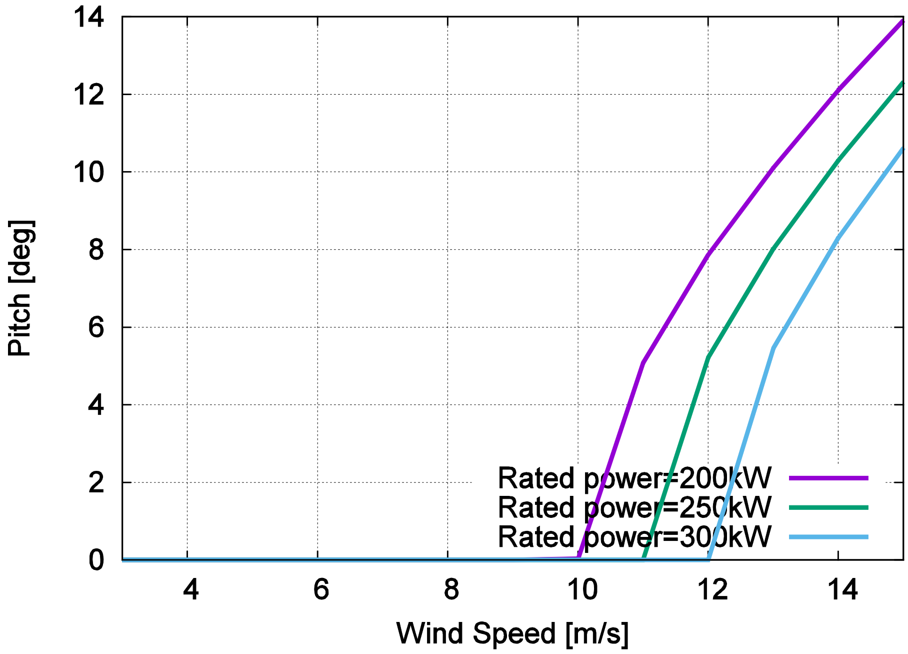

Figure 35 Pitch as a function of wind speed.

6 Load considerations

Predicting the loads that a wind turbine will experience during a lifetime is a complex matter, where many load cases have to be considered in the design process. The standard IEC 61400-1 (see www.iec.ch) is commonly used. This load standard consist of many design loads cases, where numerous events are taken into account for each of the load cases:

1. Power production
2. Power production plus occurrence of fault
3. Normal shut down
4. Emergency or manual shut down
5. Parked (standing still or idling)
6. Parked and fault condition
7. Transport, assembly, maintenance and repair

However, in this chapter a simplified approach is used. Especially one load case, stand still at 70m/s, will for different configurations of wind turbines often be the design giving or at least close to the design giving load case for many components. However, whether this load case is design giving depends on the design of the entire wind turbine and the choice of control, i.e. whether the wind turbine is stall regulated or pitch regulated and how it performs in emergency events. For the stand still load case the area of the blade is an important parameter. Comparing the projected area of the OlsenWing 14.3m blade and the V27 blade the projected areas are:

- OlsenWing 14.3m on a rotor with 30 m diameter: 11.50 m^2
- V27 13.5m on a rotor with 27 m diameter: 11.54 m^2

This indicates that even though the OlsenWing 14.3m blade is mounted on a rotor with 30 m diameter with a corresponding rotor area of 706.9m^2, the extreme loads will not be worse than for the V27 rotor with a rotor diameter of 27 m and a corresponding rotor area of 572.6 m^2. Note that the 30 m rotor has an area that is 23.4% greater than the 27 m rotor.

Results from pure aerodynamic extreme loading in stand still (e.g. no aeroelastic computations are carried out) are seen in Table 2. These loads are computed using the HAWTOPT code [i]. Here the blade root flap moment and the thrust are shown. These values do not include any safety factors and are the direct loading. It is seen that the loads are almost the same with 0.4% greater root flap moment and 2.9% less thrust force on the 30 m rotor than on the 27 m rotor. Furthermore, note that these loads are independent of control of the wind turbine. Thus, assuming that the stand still load is the design giving load case, stall regulated and pitch regulated wind turbines will experience the same extreme loading. Finally, note that rotors with blades similar to those mounted on the V27 wind turbine will experience similar extreme loading because the projected area of the blades are similar.

Table 2 Extreme blade root flap moment and thrust

	30 m rotor with OlsenWing 14.3	**27 m rotor (V27)**
Blade root flap [kNm]	266.0	265.0
Thrust [kN]	119.8	123.3

7 References

[i] *Fuglsang, P.; Thomsen, K., Site-specific design optimization of 1.5-2.0 MW wind turbines. J. Solar Energy Eng. (2001)* ***123*** *, 296-303*

[ii] *Drela, M., "XFOIL, An Analysis and Design System for Low Reynolds Number Airfoils. Low Reynolds Number Aerodynamics",volume 54, In Springer.Verlag Lec. Notes in Eng., 1989*

[iii] *Bak, C., Johansen, J., Andersen, P.B., 'Three-Dimensional Corrections of Airfoil Characteristics Based on Pressure Distributions', Proc. the European Wind Energy Conference & Exhibition (EWEC), 27. Feb. – 2. Mar. 2006, Athens, Greece*

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