Investigating the Effects of Pitch Control Strategy on the Power Electronics Lifetime of a Vertical Axis Wind Turbine

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Abstract: The power converters in Vertical Axis Wind Turbines (VAWTs) have a much shorter lifetime compared to Horizontal Axis Wind Turbines, which is due to much higher cyclic torque VAWTs experience. The blades of a VAWT can be pitched at different points in the cycle to reduce the magnitude of the cyclic loading. This paper investigates how the application of various pitch regimes affects the lifetime of Insulated Gate Bipolar Transistors (IGBTs) and diodes within the power converter. Testing was done using StrathDMS and an IGBT module thermal model. The results show that the both Coefficient of Performance (Cp) and converter lifetime can be increased by using a pitch regime that maintains high torque, while the torque ripple is kept low. It was also found that the torque ripple can be reduced by operating at a slightly higher Tip Speed Ratio (TSR).

Double Multiple Streamtube model of a VAWT devised by Soraghan [1]

Considers wind shear, dynamic stall, and tip loss

Rotor geometry, airfoil, wind speed and pitch regime can be varied

StrathDMS

The main outputs are Cp and rotor torque

Torque output from the model is shown in Figure 1

Power electronics lifetime prediction

Thermal model of IGBT components, predicting the lifetime

Uses torque from StrathDMS to calculate IGBT voltages and currents

Tests show diode lifetime is always shorter than IGBT

IGBT model

Model's output – diode temperature is shown in Figure 2

Rainflow counting is used to calculate the cumulative damage

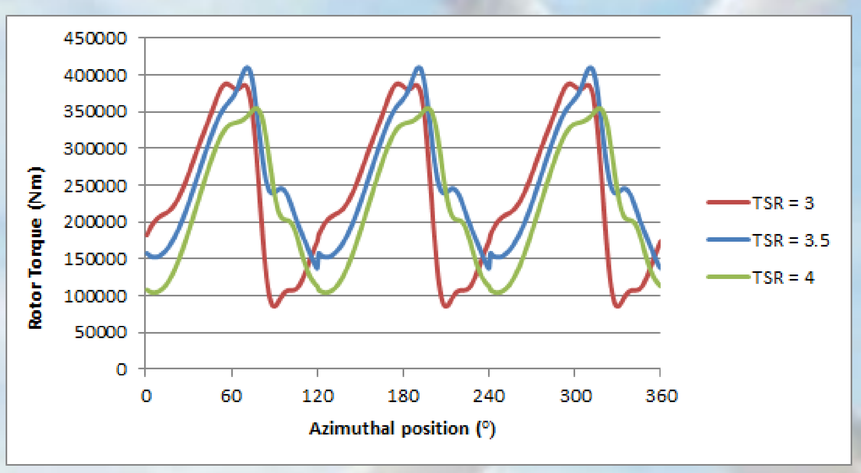

Figure 1. Torque vs azimuthal position for different TSRs.

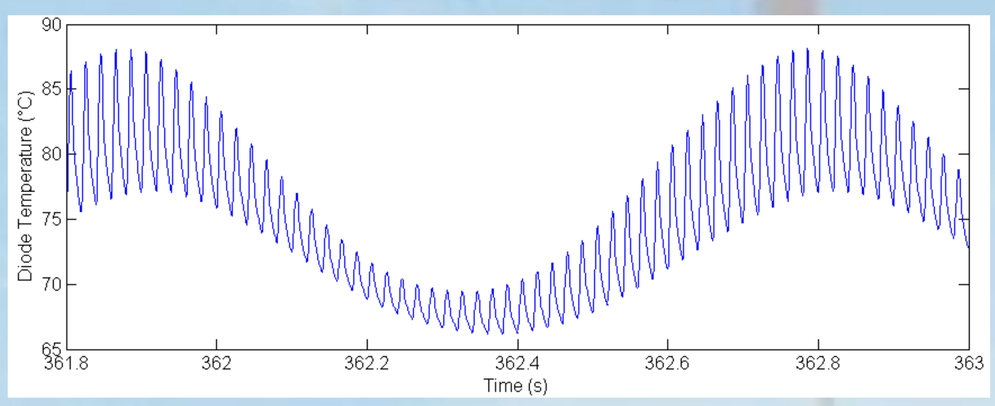

Figure 2. Diode Temperature vs time, with high frequency variations, due to switching and low frequency variations, due to torque input profile.

Results

In total, 26 different pitch regimes were devised and tested. The Cp and diode lifetimes for each pitch regime are shown in Figure 4. is important to understand what makes some pitch regimes perform better than others, both in terms of Cp and diode lifetime.

Pitch regimes 14 and 25 have a very similar Cp (0.35 and 0.349 respectively), but different diode lifetime (15.1 years and 6.8 years respectively). To understand what causes the difference, a closer look at the rotor torques produced by each pitch regime is required, which is shown in Figure 3. It can be seen that the range of torques for pitch regime 25 is higher than pitch regime 14; it is this high peak value of torque range that reduces the diode lifetime.

However, the Cp values of both pitch regimes are very close, as although pitch regime 25 has a higher maximum torque, the blue line of pitch regime 14 is above the orange line in the regions near 0, 120 and 240°, compensating for the lower maximum torque.

A more in depth analysis can be conducted by looking at angles of attack along the azimuthal position, which often explains why some pitch regimes perform better than others, as it allows to identify whether the blades stall at any point of the cycle or whether the angle of attack is too low to extract sufficient energy to obtain a high Cp.

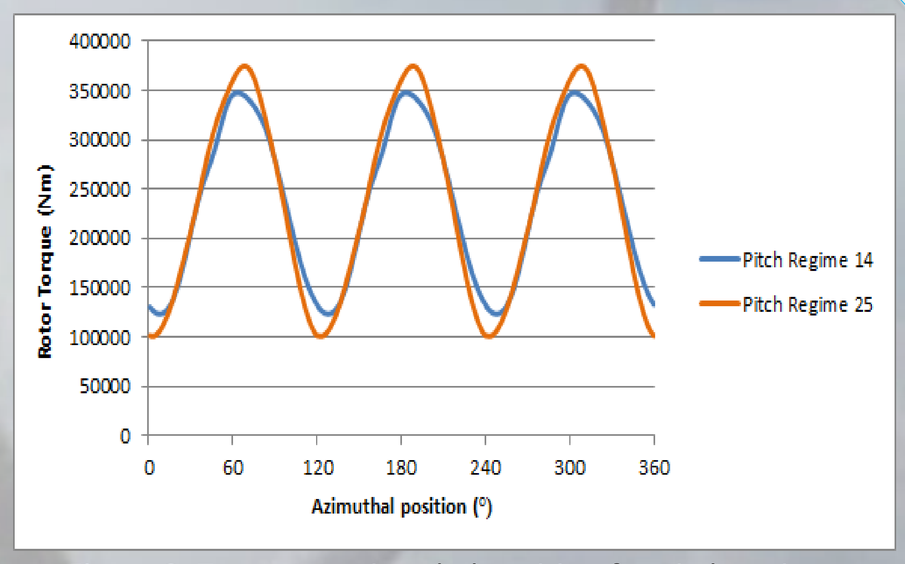

Figure 3. Torque vs azimuthal position for pitch regimes with similar Cp.

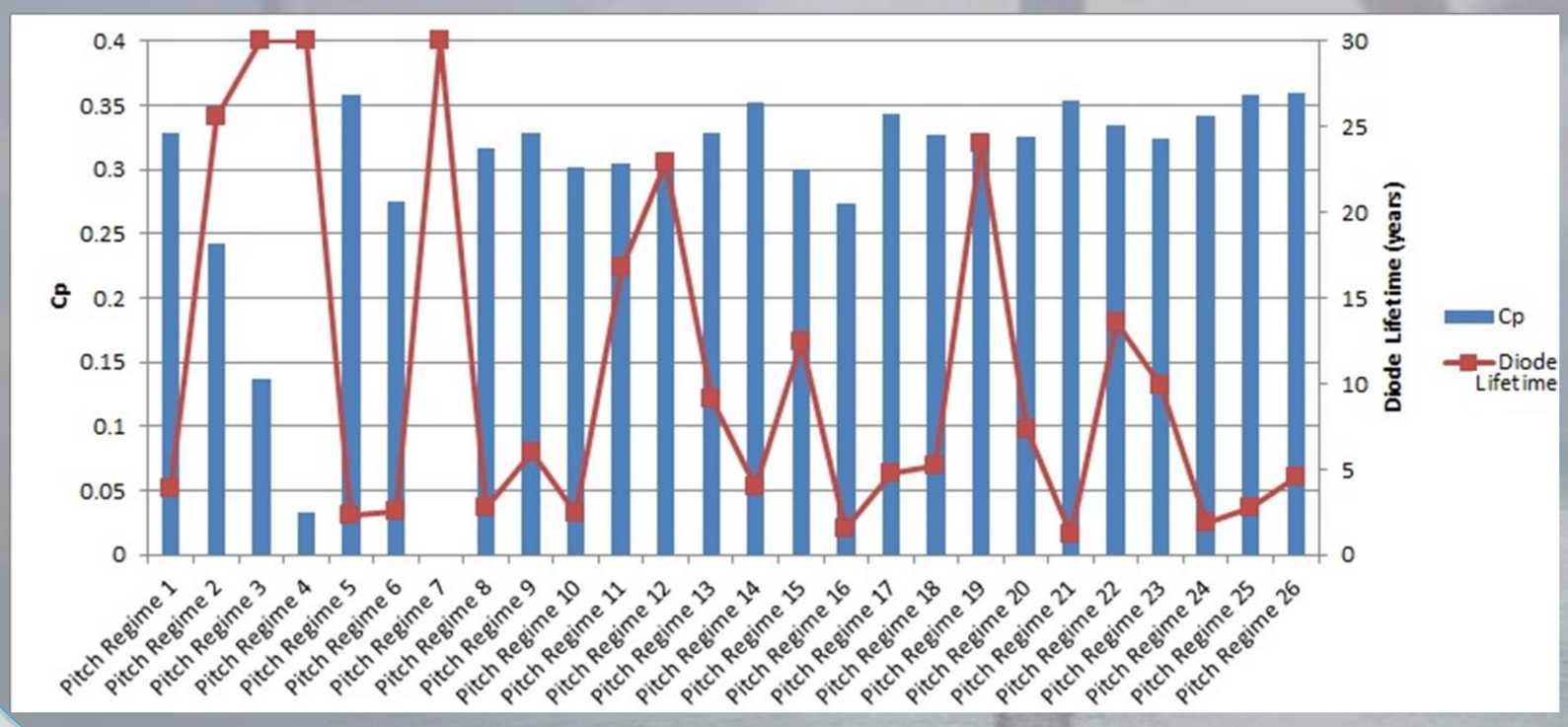

Figure 4. Cp and diode lifetimes for various pitch regimes.

Conclusions

It was concluded that:

- Smoothing the torque ripple, by applying appropriate pitch regime, can increase the lifetime of power electronics.
- TSR of 4 is recommended, as it reduces the torque ripple, while still achieving high Cp values.
- Using the right pitch regime can increase the lifetime of power electronics by 180% for the same Cp, compared to no pitch regime.
- Pitch regimes can be optimised by looking at Angle of Attack (AOA) at different points of the cycle
- For best performance and power electronics lifetime, AOA should be higher downstream than upstream, should never exceed ~13°.

EPSRC Engineering and Physical Sciences Research Council

[1] Soraghan, Aerodynamic Modelling and Control of Vertical Axis Wind Turbines. CDT in Wind Energy Systems, University of Strathclyde, 2014.