

New Pitch Control Method for Aerodynamic Improvement in Case of Flow Misalignment (for Floating Turbines)

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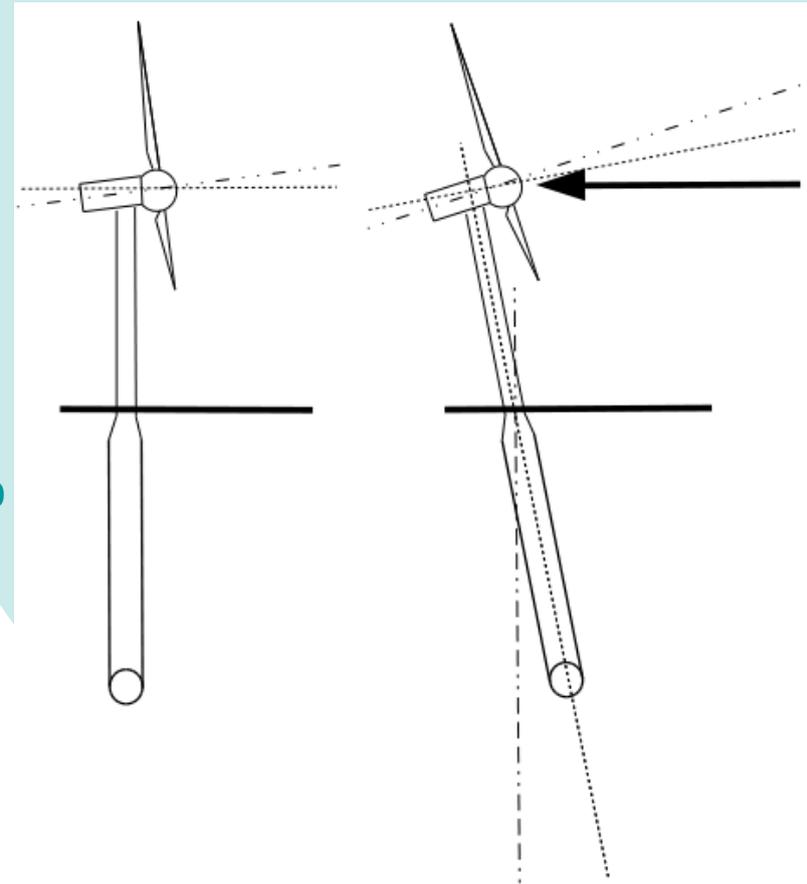


Wind Farm Analytics



FLOATING ONSHORE(!) TURBINES

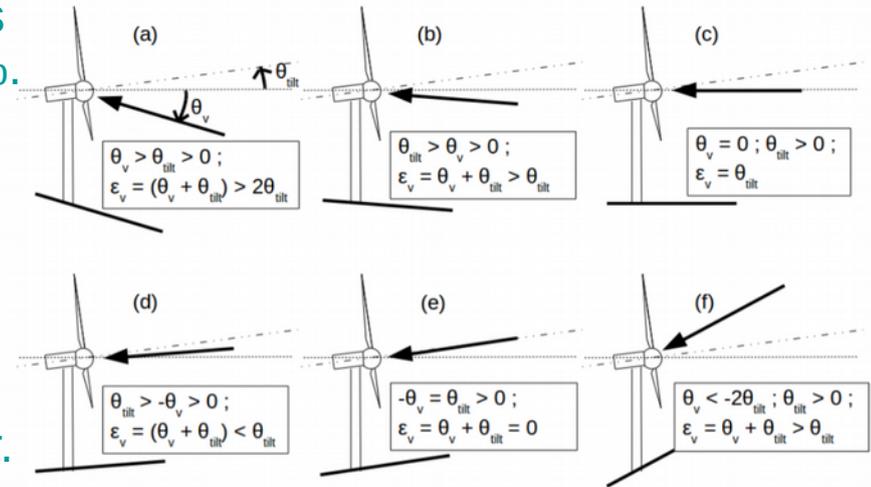
- Floating offshore wind turbines are very similar to onshore wind turbines mounted on a floating foundation.
- This presentation will discuss how onshore wind operational learning can be applied to floating turbines.
- The industrial “horizontal axis wind turbine” has its rotor plane tilted (typically 5°) to the vertical and therefore its rotor axis tilted (typically 5°) to the horizontal.
- This design feature has reason to avoid blades flexing to the extent that they strike the tower and kill the ‘mill.
- But modern industrial turbines are axial flow turbines and any angular misalignment between wind flow and rotor axis introduces inefficiency.
- For floating turbines flow misalignment may be made worse by thrust force tilting the turbine back in the water.





NON-HORIZONTAL FLOW LOSSES

- Onshore wind farms in hilly locations produce similar conditions to floating turbines!
- Roughly speaking the wind follows terrain, sometimes even favourably wrt rotor axis [Fig.(e)].
- Turbines witness varying angular flow misalignments according to horizontal wind direction.
- Operational data analysis shows quite gentle slopes give rise to significant production losses such as 5%.
- Often the slopes can lead to ~10% production losses worth typically £1 million or more per UK 2MW turbine with 20 years lifetime.
- For larger turbines (eg 4+ MW) losses are greater.
- For longer lifetimes (eg 30 years) losses are greater.
- This is the vertical equivalent of running turbines with a permanent horizontal yaw error/misalignment.



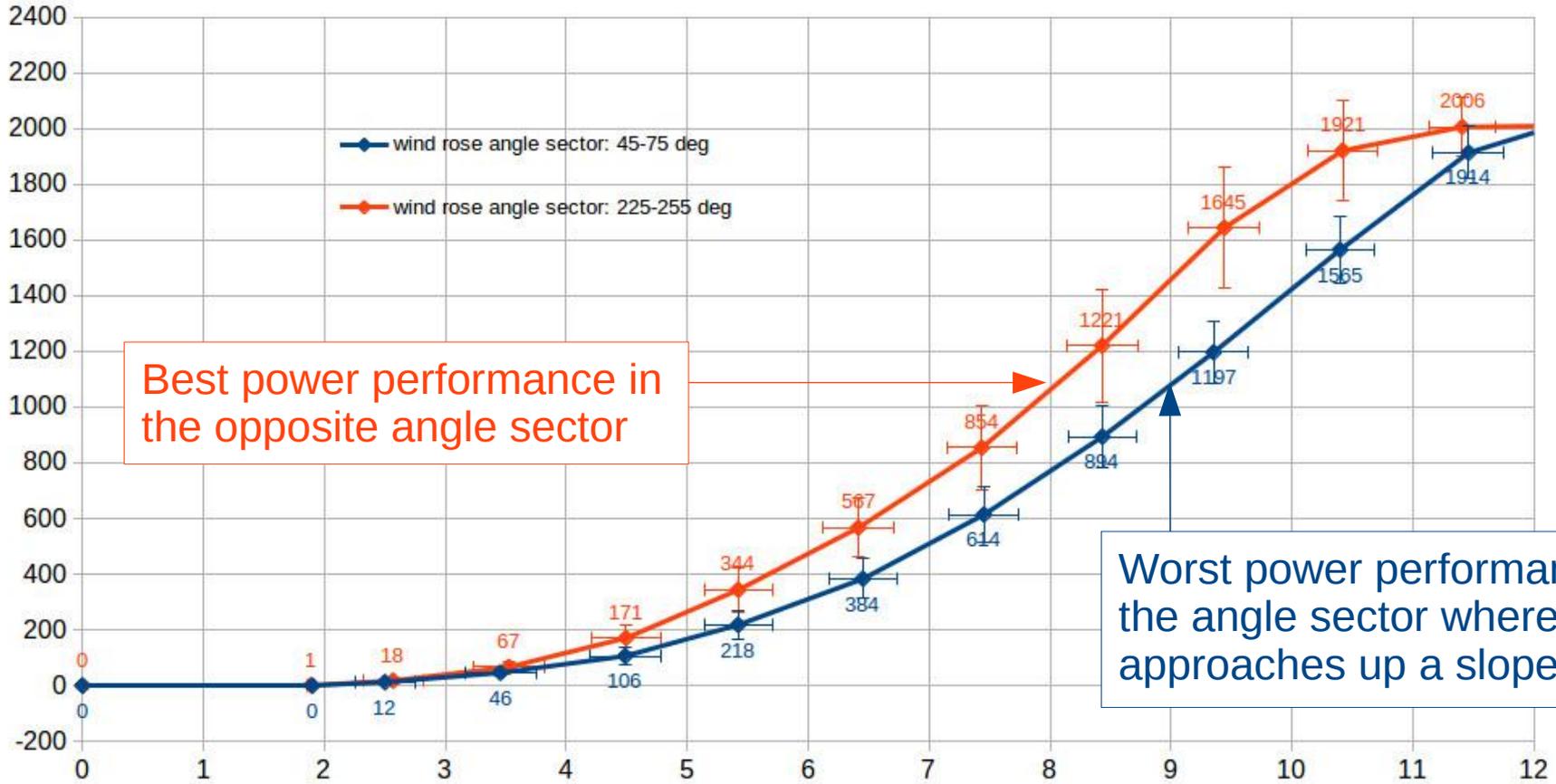


HOW DO WE KNOW THIS?

- It is easy to prove and quantify this per (hilly WF) turbine once we have operational data.
- We simply split the power curve data into 12x (horizontal) 30° wind direction sectors.
- We can then compare power performance in each sector, each with its own terrain slope.
- However, the interesting thing is that we see many turbines where the minimum performance is exactly when the wind is coming up a slope underneath the turbine.
- This can be understood because the turbine rotor axis is typically tilted upward ~5°.
- When wind flows up a slope under the turbine then axis tilt increases the misalignment.
- There are many possible reasons for under-performance but if repeatable worst performance is when wind comes up the slope, then in the absence of other explanations, you can be confident the **DOMINANT** cause of losses is vertical flow inclination.



POWER CURVE PROOF



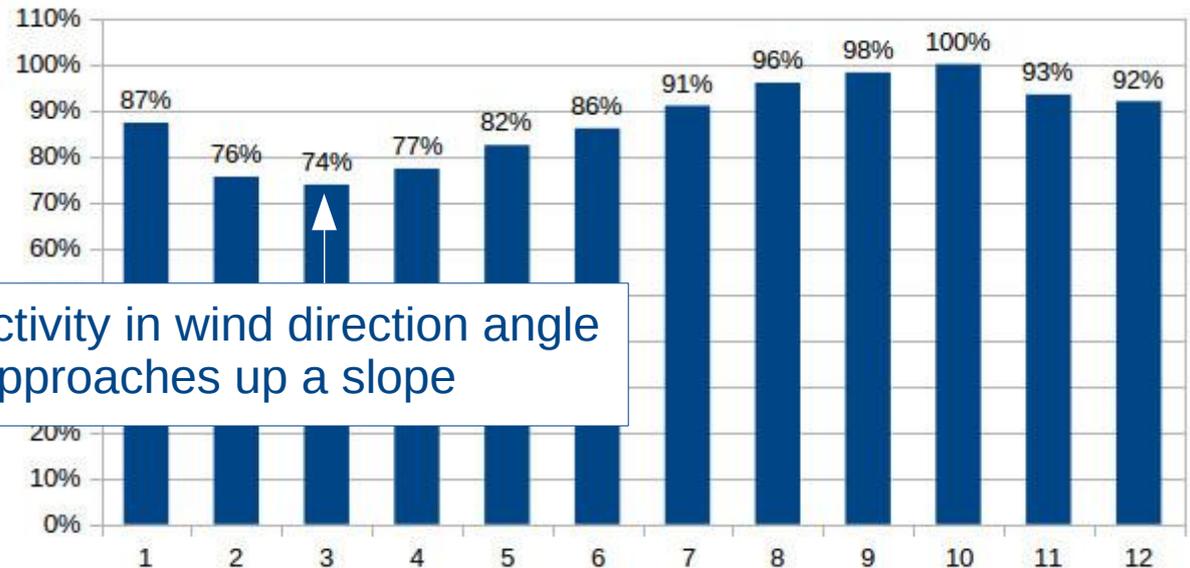
Best power performance in the opposite angle sector

Worst power performance in the angle sector where wind approaches up a slope



QUANTIFY LOSSES PER TURBINE

- Its easy to convert power curve into productivity per (12x) 30° wind direction/yaw sector.
- For turbines on a consistent slope it is common to see a sinusoidal wave effect with the lowest productivity when the wind flows uphill and the best productivity in opposite sector.
- Some people questioned whether its due to wakes but wake sectors were calculated and found to be insignificant.
- Note: some turbines exhibit a more complicated picture due to the terrain being very complicated.

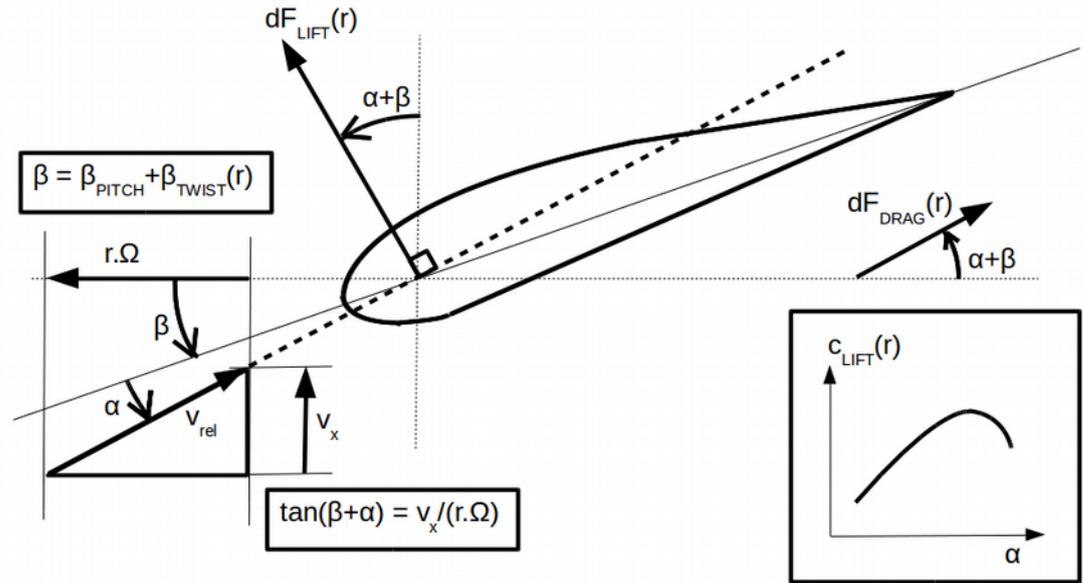


Worst energy productivity in wind direction angle sector where wind approaches up a slope



EXPLANATION: AERODYNAMICS

- Imagine you are an elf with x-ray vision sitting on the tip of the blade and looking toward the rotor centre!
- Focusing on a blade element around halfway along the blade you notice...
- The blade element speed within rotor plane ($r\Omega$) may be greater than axial wind speed (v_x) driving the turbine.
- These perpendicular airspeed components form a velocity triangle which defines the aerodynamic angle of attack, α (and therefore lift force).
- Note: Turbine controller uses blade pitch motor control (β) to govern α .

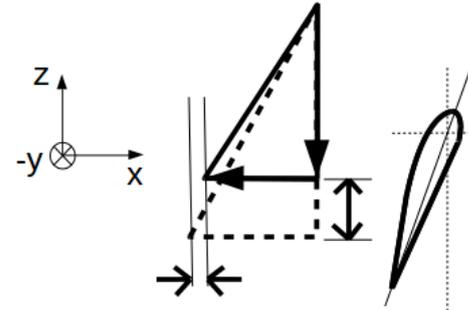




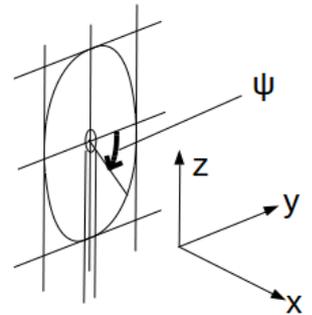
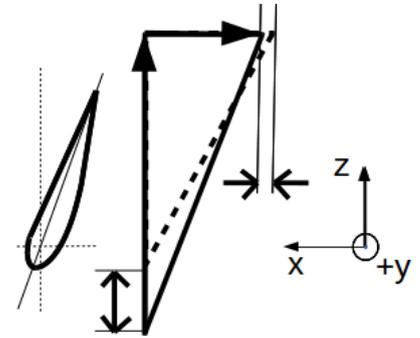
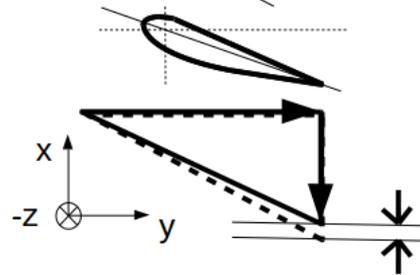
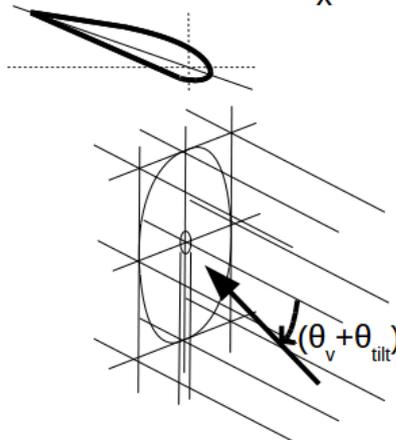
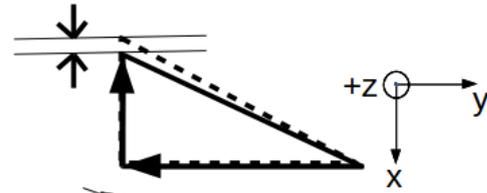
MORE:

- The key thing to notice is that when wind flows up a slope then the velocity triangle varies cyclically as the blade travels around the rotor.
- When blade travels down (RHS) the relative airspeed is increased in the rotor plane and when the blade travels up (on LHS) this airspeed is decreased.
- The cyclic change in this triangle means the angle of attack has a cyclic error which causes loss of lift.

$$\begin{pmatrix} v_x \\ v_y \\ v_z \end{pmatrix} = \begin{pmatrix} v \cdot \cos(\theta_v + \theta_{\text{tilt}}) \\ 0 \\ v \cdot \sin(\theta_v + \theta_{\text{tilt}}) \end{pmatrix}$$



$$\tan(\beta + \alpha) = \frac{v \cdot \cos(\theta_v + \theta_{\text{tilt}})}{(r \cdot \Omega + v \cdot \sin(\theta_v + \theta_{\text{tilt}})) \cdot \cos \psi}$$





WHAT CAN WE DO ABOUT IT?

- For hilly wind farms steep slopes should be avoided in favour of less steep slopes during planning and development. You wouldn't run your turbine deliberately with an avoidable horizontal yaw error so why would you allow equivalent misalignment in the vertical plane?
- However many sites may be unavoidably hilly and the developer naturally wants as many (anyway profitable) wind turbines as possible for maximising green revenue.
- But if we can get significantly more wind energy at low cost then its logical to do so. The good news is that where there is a cyclic error on the aerodynamic angle of attack we can correct it using an opposite cyclic adjustment with the blade pitch control systems.
- The same solution can be applied to floating turbines and it could be worth even more!
- This can add value during planning of wind farms, or by upgrade / retrofit of existing turbines.
- Upgrade can be achieved by working with turbine suppliers, or via independent specialists.
- Tune up your wind turbine performance parameters like a racing car!



FLOATING APPLICATION

- We can obtain similar percentage gains for floating turbine as with hilly onshore turbines for the simple geometric reason that floating tilt angle is of similar magnitude as terrain angles.
- But bigger turbines, higher capacity factors, and the fact that flow misalignment is present for all wind directions (unlike hilly wind turbine locations where it is reduced for some wind directions) we can expect the monetary value to be much higher for floating turbines.
- Additional to (a) the thrust force causing increasing tilt with increasing wind speed, there are (b) variations and oscillations in tilt angle due to variable wind and variable wave motion.
- It is noted that increased average wind speed is a main reason to deploy floating turbines.
- ...and that increased wind speed is often associated with increased wave motion (incl. tilt).
- Mathematically we can account for the full 6 DOF motion (roll, pitch/"tilt", yaw, surge, heave sway) of the floating foundation. Operationally these parameters can be supplied by sensors.
- Motion will vary according to different foundation designs and different deployment conditions but we can account for all possibilities. Lets make this global improvement!



INDUSTRY FEEDBACK (more available)

- Director, UK Wind Farm Owner/Developer: "[WFA is] speaking common sense, owners would be ready to do profit sharing deals with turbine manufacturers";
- World Leading Control Specialist, Certification Provider: "[WFA is] quite right - pitch control can be used to compensate for change in aerodynamic angle of attack";
- Senior Expert in Loads and Optimisation, Major EU Wind Turbine Manufacturer: "[WFA] idea is quite interesting";
- Control Engineer, EU Control Specialist: "we like the idea, see potential, have successfully checked it with computer simulations and are now working on implementation at a multi-MW turbine";
- Loads & Measurement Engineer, EU Wind Turbine Manufacturer: "Maths and physics is clear - we see the potential";
- Aerodynamic Engineer, EU Blade Specialist: "totally convinced, it totally makes sense";
- CTO, EU/Chinese Wind Technology Co: "The [WFA] method can work and has potential for handling combinations of shear, yaw, upflow, etc";



COMMERCIAL OPPORTUNITIES

- Wind turbine buyers are ready to do profit sharing deals with turbine suppliers.
- There is an avalanche of customer opportunity waiting to be triggered.
- Wind turbine manufacturers can obtain competitive advantage by offering this option.
- This option can open up new markets (such as in steep terrain).
- The blade pitch motor methods can be beneficially applied to floating offshore turbines.
- Wind turbine certification limits can be broadened to a larger operational envelope.
- LIDAR manufacturers can offer new services.
- Wind farm developers obtain option to add value to their projects during the planning stage.
- Automatic SCADA data processing can identify lead upgrade candidates and quantify value.
- Automatic data processing can identify upgrade candidates and value during planning.



INNOVATION PARTNERSHIP?

- Wind farm Analytics is ready to join existing or new research/demonstration collaborations to demonstrate and study this opportunity in the context of floating wind turbines.
- In cases where floating, offshore or onshore wind farm consent process favours inclusion of beneficial innovation then we can certainly offer that.
- Optionally we are ready to work with floating foundation providers on given design application.
- Optionally we are ready to work with turbine suppliers on developing the new commercial and technical options which we have discovered.
- Optionally we are ready to work with turbine suppliers, developers and owners to automate calculation of upgrade value per turbine and automate calculation of upgrade parameters.
- Optionally we are ready to work also with existing LIDAR suppliers to obtain further gains by use of this pitch control method including also LIDAR data.
- Optionally we are ready to expand our academic collaboration (Birkbeck, Univ. of London)



CONCLUSIONS

- The wind industry does not pay sufficient attention to non-axial wind flow.
- This is seen from many met masts still employing instruments measuring only horizontal wind speed and direction (eg spinning cups). 3D converging beam LIDAR would be better.
- By taking 3D flow into account there is opportunity to increase asset energy yield and value.
- For many wind turbines in hilly situations this could be worth up to 10% of energy production.
- We can earn up to £1 million or more extra per onshore hilly turbine lifetime at cost of software update. This can be even more valuable for large floating turbines!
- Further advantages include load/vibration reduction, leading to less failures in operation, reduction of downtime/maintenance costs and increasing overall asset lifetime.
- Wind Farm Analytics Ltd has patented a family of related control methods.
- Wind Farm Analytics Ltd seeks partners and/or investors for demonstration & global roll-out.



Join us on our journey

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