New wind turbine control upgrades arising from converging beam LIDAR research

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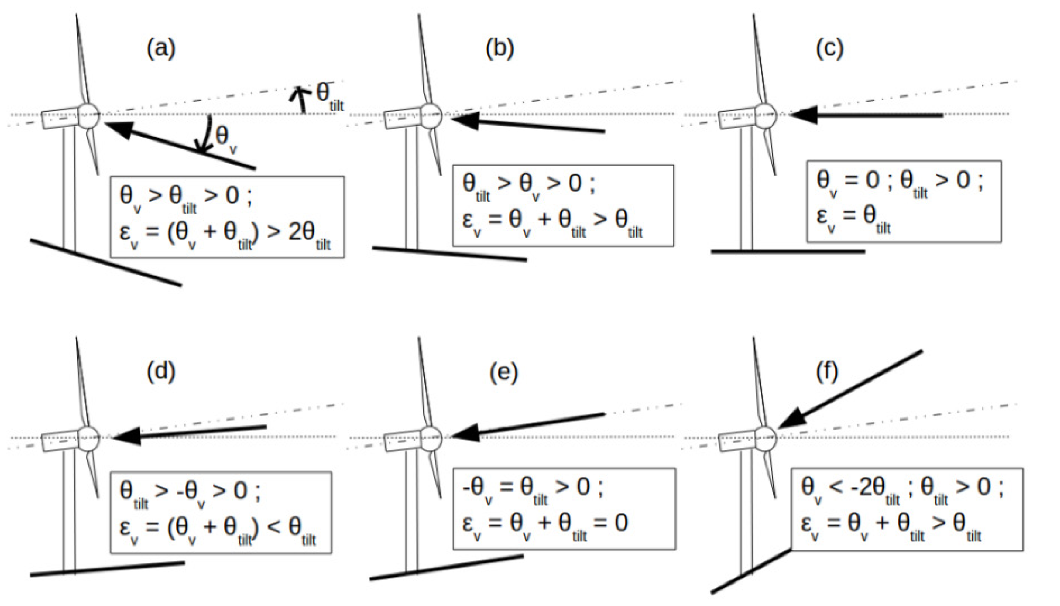

Fig 1: Axial flow turbines respond best to fluid flow parallel to rotor axis but especially in hilly terrain significant angular misalignments are common

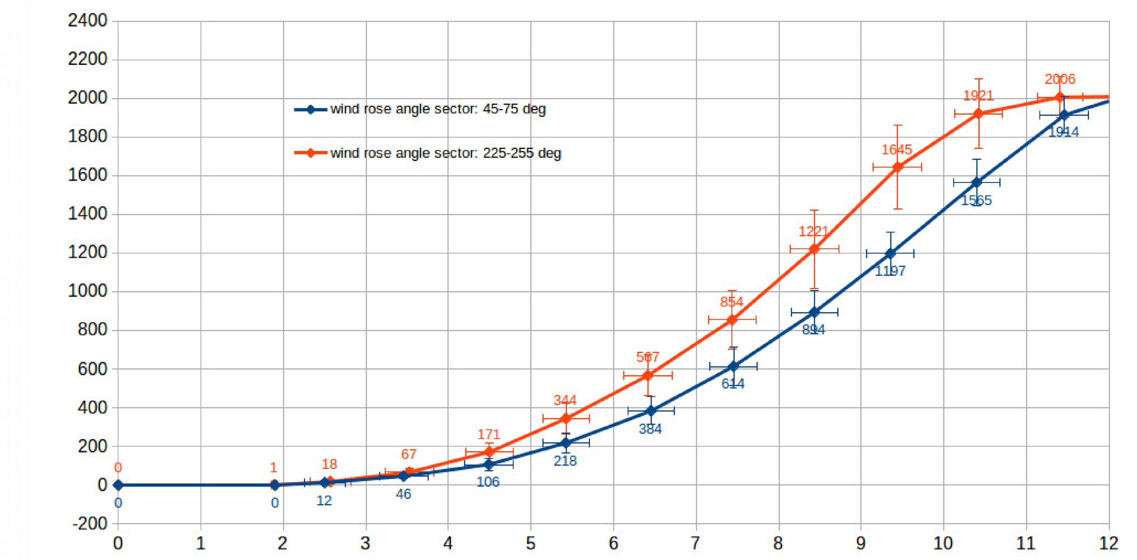

Fig 2: Real life operational data shows much worse power curve performance from angle sectors where wind is flowing up the slope (blue) compared to flowing down the slope (red)

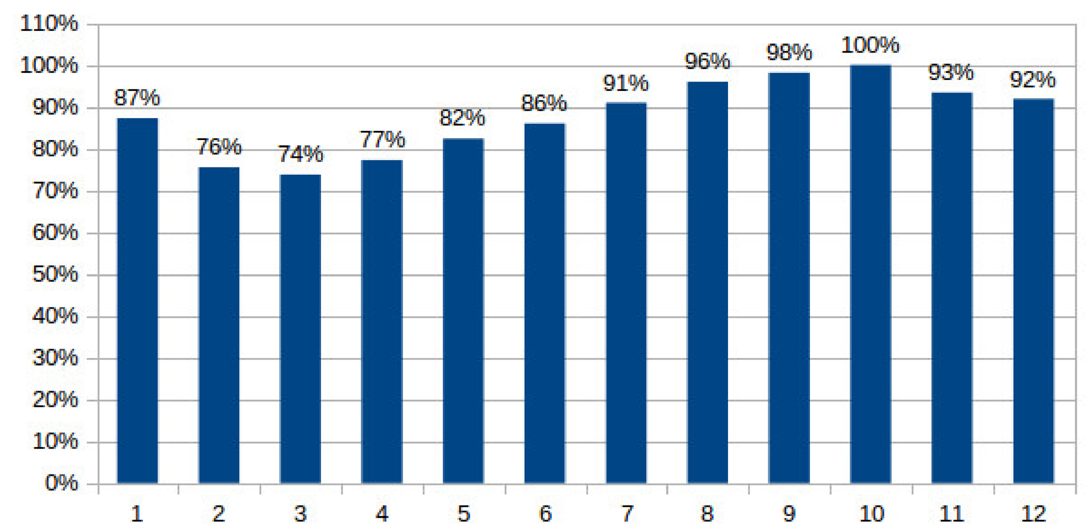

Fig 3: Splitting operational data for a given turbine into 12x 30 degree horizontal angle sectors we can convert the 12x sector power curves into an energy productivity metric displaying the variation according to approaching terrain slope

Birkbeck, University of London, and Wind Farm Analytics Ltd collaborate on converging beam LIDAR research in relation to three-dimensional laser wind measurement[1,2]. Converging beam LIDAR offers new opportunities for increasing the productivity of wind farms, both onshore and offshore.

But in research it is often the case that work in one area gives rise to new inventions[3] in another area. In our case contemplation of three-dimensional wind measurement by use of LIDAR led us to focus on hilly wind farms where three-dimensional flow effects are particularly evident. We studied data from turbines in hilly locations in order to highlight the operational data signals which clearly confirm the importance of 3-dimensional wind flow. We show this evidence using operational SCADA data (Figs. 2 & 3) to quantify that wind energy losses due to non-horizontal flow (Fig. 1) are frequently costing up to 10% of lifetime energy production, worth £1 million per turbine for many turbines. Sceptics have argued that nothing can be done about this so we emphasised converging beam LIDAR can be used to directly measure vertical flow inclination wind statistics at the planning stage so as to optimise micro-siting of wind farm layout. This remains an option but others have argued that once the layout of a wind farm is fixed or the turbines are installed then there is nothing to be done. However, something can be done. We highlight that angular flow misalignments translate into sub-optimal aerodynamics and that there is indeed a simple yet beneficial pitch control solution available to the global wind industry.

A simple control software solution – how does It work and what opportunities does it offer?

The modern industrial wind turbine is an axial flow turbine which responds best when wind flow is parallel to the rotor axis. Any angular misalignment with respect to rotor axis translates geometrically into a known cyclic error in aerodynamic angle of attack (Figs. 4 & 5), resulting in loss of aerodynamic lift and loss of output power. By further utilising existing blade pitch motorisation we can correct the angle of attack to cancel the error and thereby increase output power. This is typical of Scottish hilly wind farms but is quite common globally to varying extents. The green energy market value is commonly around £1 million per turbine. Therefore the global wind energy upgrade opportunity from this research innovation is of significant potential.

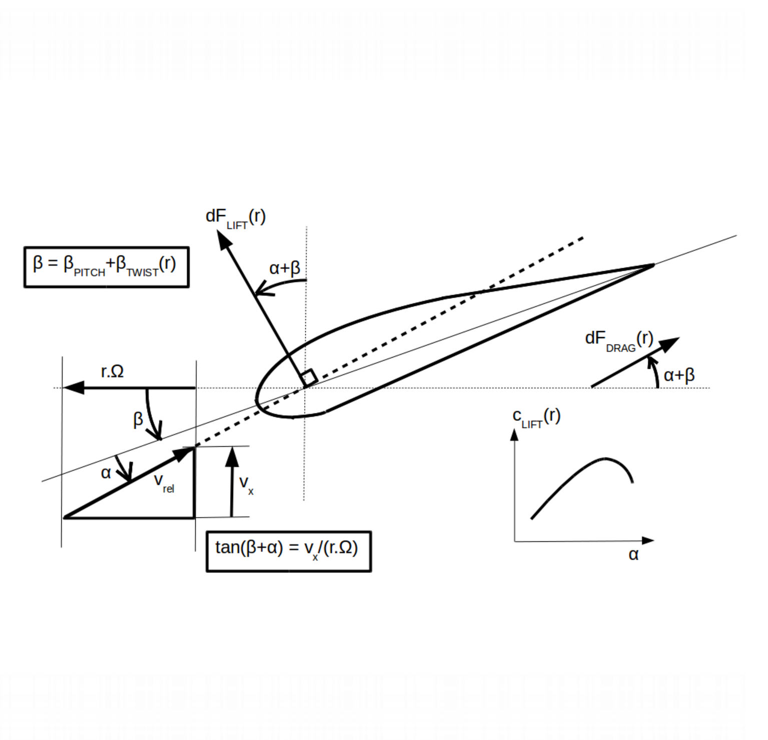

Fig 4: Axial wind speed and blade rotation within rotor plane form a right angled triangle defining angle of attack and therefore aerodynamic lift

There are many further applications both onshore and offshore, either with LIDAR or without LIDAR, whether in planning or in operation. For large rotors the standard rotor tilt angle alone implies losses of around 1% on the rise of the power curve. Floating turbines are a very interesting case since their tilting motion (which can be measured using sensors) causes a dynamically changing axial flow misalignment angle, which can be dynamically adjusted for. In the case of hilly wind farms onshore there is a static, constant, and predictable component because the terrain slope is constant and known. In the floating case the misalignment is also known since it can be measured with sensors. Identification of lead candidate turbines and quantifying the energy uplift opportunity can be automated at the planning stage or from SCADA data during operation. Converging beam LIDAR offers additional gains via ***direct measurement*** of flow inclination.

The authors engage extensively with wind industry participants, and have obtained overwhelming positive feedback confirming technical & commercial potential. Some examples are here provided:

- Director, UK Wind Farm Owner/developer: "common sense, owners would be ready to do profit sharing deals with turbine manufacturers"
- Senior Expert in Loads & Optimisation, EU Wind Turbine Manufacturer: "idea is quite interesting"
- Control Engineer, EU Control Specialist: "working on implementation at a multi-MW wind 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"
- Chief Technology Officer, EU/Chinese Wind Technology Company: the method can work and has potential for handling combinations of shear, yaw, up-flow, etc"
- World Leading Control Specialist, Certification Provider: "quite right - pitch control can be used to compensate for change in aerodynamic angle of attack"

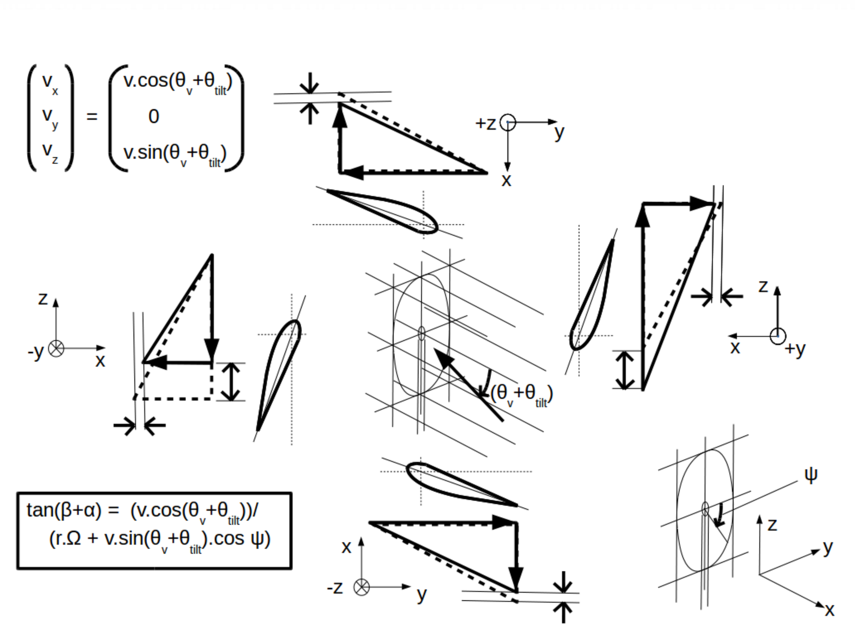

Fig 5: Flow inclination results in cyclic error in AOA which can be easily corrected via pitch control

Conclusion

Wind turbine controllers can be easily tuned for their specific flow inclination neighbourhood. There are global opportunities to harvest significant further wind energy through a simple low cost software upgrade. The authors seek partnerships toward further related research and global deployment.

1 Holtom & Brooms, "Error propagation analysis for a static convergent beam triple LIDAR", Applied Numerical Mathematics, 2020.
2 Brooms & Holtom, "Volumetric uncertainty bounds and optimal configurations for converging beam triple LIDAR", App. Num. Math., 2020.
3 Holtom, "A turbine provided with data for parameter improvement", PCT International Patent Filing WO2022/171997A1, 09 Feb 2022.