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Research Question n.44

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Research Question

What is the impact of blade flexibility in a wind turbine blade optimization problem?

Short Answer

Wind turbine efficiency can decrease when operating outside the design parameters, which is particularly problematic for tiny fixed-pitch, constant-speed devices and those running in very variable winds.

Recent breakthroughs in adaptable structure design have given rise to a novel turbine idea that uses continuous form morphing to adapt more efficiently to changing conditions. These morphing blades might help tiny wind turbines become more economically feasible by increasing efficiency over a wider range of wind speeds and tip-speed ratios.

Executive Summary

For thousands of years, people have been exploring the ways of using wind energy, from using wind energy to grind grain to today using wind turbines to generate electricity. The wind energy industry, in particular, has witnessed extraordinary development among renewable energy sources that have grown increasingly popular for power conversion in recent years. In 2021, the global new installed capacity reached 93GW.

As well known, the efficiency of the wind turbine is only possible to reach the maximum under the design conditions, and once it operates in deviation from the design conditions, the efficiency will drop sharply, and even the turbine will be shut down.

For large-scale wind turbines, many solutions are used to offset these losses， such as blade pitch and torque control systems. But such control systems are often expensive, and small wind turbines cannot afford the high cost. Hence, we need a technology to improve the efficiency of small wind turbines operating under non-set conditions.

According to new study into flexible bladed wind turbine rotor design, continuous, passive blade morphing can boost aerodynamic lift, reduce drag, and even delay stall for two-dimensional airfoil sections. These morphing blades might help tiny wind turbines become more economically feasible by increasing efficiency over a wider range of wind speeds and tip-speed ratios. As a result, it may be worthwhile to make flexibility a design parameter for future turbine development.

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1. Introduction

Wind turbine systems are designed to perform best under specified environmental conditions, such as wind speed. Variable wind speeds are imposed by changing weather conditions, and as a consequence, turbines spend the majority of their time working at off-design circumstances, which can have a considerable impact on efficiency.

By looking up the literature, we learn that recent breakthroughs in adaptive structure design have given rise to a new turbine concept that uses continuous shape morphing to allow the blades to adapt to changing aerodynamic circumstances effectively. This new morphing blade design has the potential to outperform fixed geometry airfoils.

The impact of blade flexibility in a wind turbine blade optimization problem is the subject of this text. This article focuses on the experimental results of predecessors and summarizes them.

2. Wind energy utilization

2.1 History

For thousands of years, people have used wind energy in a variety of ways. In the early days, people used wind energy to do things such as pumping water, and more recently, wind turbines were used to generate electricity.

Figure 2.1 –Wind energy applications

(resource: Lecture of Wind Energy Introduction)

There has been evidence of individuals employing wind energy from the beginning of recorded history. Ancient Egyptians were among the first adopters, using the wind to drive boats along the Nile River as early as 5,000 B.C. Persians employed wind-powered mills to pump water and grain between 500 and 900 B.C.

In 1888, Charles Brush constructs the world's first large-scale wind turbine, with a 17-meter diameter wind rose and a 12-kilowatt engine. From the 1920s to the 1950s, propeller-type 2- and 3-blade horizontal-axis wind power conversion systems were widely used.

The two oil crises have made people aware of the instability of dependence on fossil fuels, thereby increasing the development and application of clean energy.

2.2 Current status

In overall, wind turbines have had a lot of success recently. As we can see from Table 2.1, the wind energy generation capacity of countries around the world has increased significantly, and the global wind energy power generation has increased from 28.35TWh in 2000 to 383.21TWh in 2019, and it is still increasing year by year.

Table 2.1 – Change in wind energy generation

Country	2000 (TWh)	2019 (TWh)	Absolute change (TWh)	Relative change
Africa	0.43	7.84	+7.41	+1,707%
China	0.32	95.45	+95.13	+29,451%
France	0.03	15.58	+15.55	+50,155%
Germany	11.07	38.67	+27.60	+249%
Italy	0.44	5.65	+5.20	+1,172%
World	28.35	383.21	+354.86	+1,252%

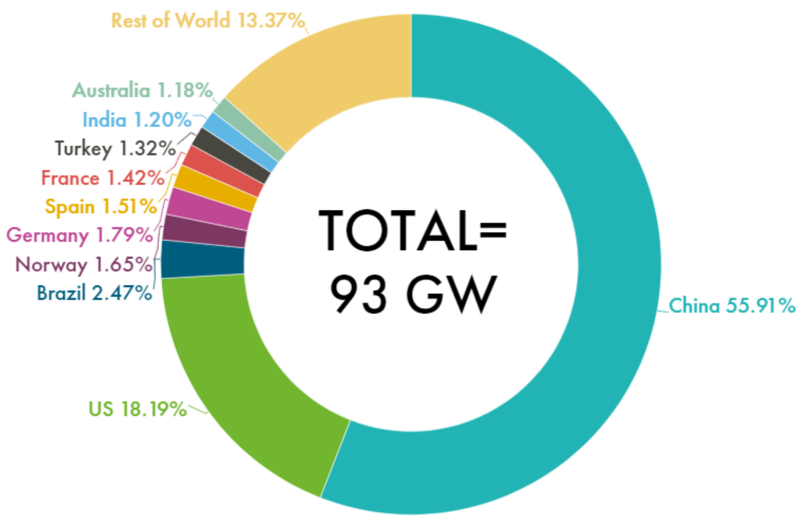

Figure 2.2 – New global wind installation (2021)

(resource:《Global wind report 2021》)

3. Blade flexibility

3.1.1 Power of wind turbine

The turbine power curve is divided into four primary regions:

Region 1: the wind speed is slower than the cut-in speed, hence the turbine produces no power.

Region 2: after the cut-in speed, power production begins. The curve is determined by the control approach used. The produced power is less than the wind power because to the Betz limit.

Region 3: when the rated power of the generator is attained, the turbine is operated to harvest the rated power until the cut-out speed is reached.

Region 4: Mechanical loads on the turbine blades are too large at the cut-out speed, so the turbine is managed to slow down for structural reasons.[1]

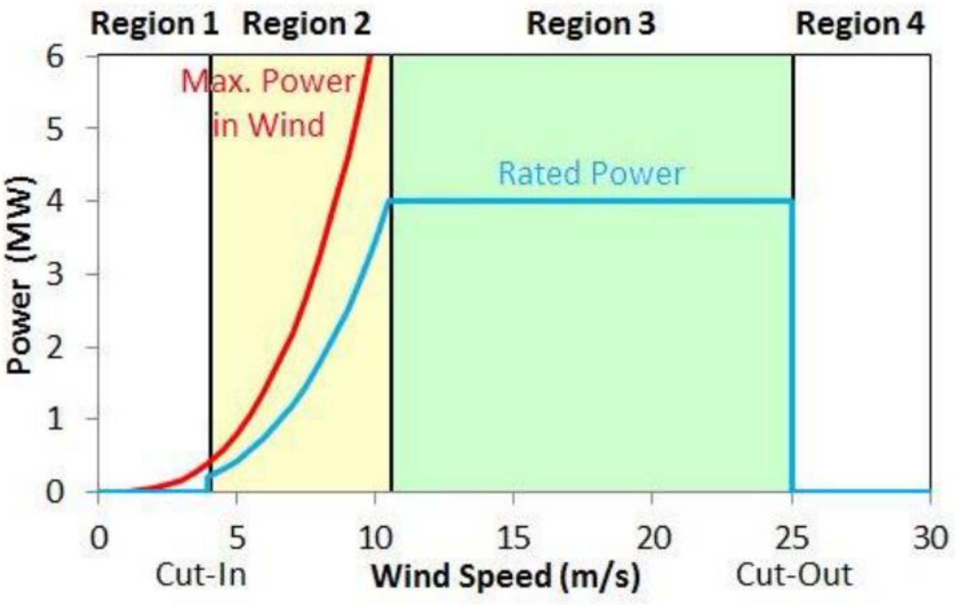

Figure 3.1 –power curve

(resource: Lecture of Wind Energy Introduction)

Therefore, the efficiency of the wind turbine is only possible to reach the maximum under the design conditions, and once it operates in deviation from the design conditions, the efficiency will drop sharply, and even the turbine will be shut down.

"Hence, a systemable to effectively convert the kinetic energy inherent in wind flow to shaft energy which drives a generator over a passable range of weather conditions is desired."[2]

Many solutions have been used to offset these losses, such as blade pitch and torque control systems, however such systems are expensive and are normally only used in larger scale applications. Pitch control solutions are either too sophisticated or not economically practical for tiny Horizontal-Axis Wind Turbines and most Vertical Axis Wind Turbines.

According to new study into flexible bladed wind turbine rotor design, continuous, passive blade morphing can boost aerodynamic lift, reduce drag, and even delay stall for two-dimensional airfoil sections. These morphing blades might help tiny wind turbines become more economically feasible by increasing efficiency over a wider range of wind speeds and tip-speed ratios.

3.1.2 Previous and Related studies

In the study by David W. MacPhee and Asfaw Beyene, experimental data were used to analyze the utility of turbine flexible blades. "Experiments are conducted comparing a prototype rigid bladed design to an identical flexible one, with a total of 18 data sets containing 230 data points." [3]

Experiments were carried out at San Diego State University's Large Diameter Wind Tunnel laboratory. Rigid blades were created with a rigid substance that does not flex when in use. "The morphing material is a flexible polyurethane with density 1050 kg/m3, Poissons ratio 0.4 and Youngs modulus 1.86 *10^5 Pa. " [4] The experiment uses 3 sets of different pitch angles and wind speeds to compare flexible and rigid blades.

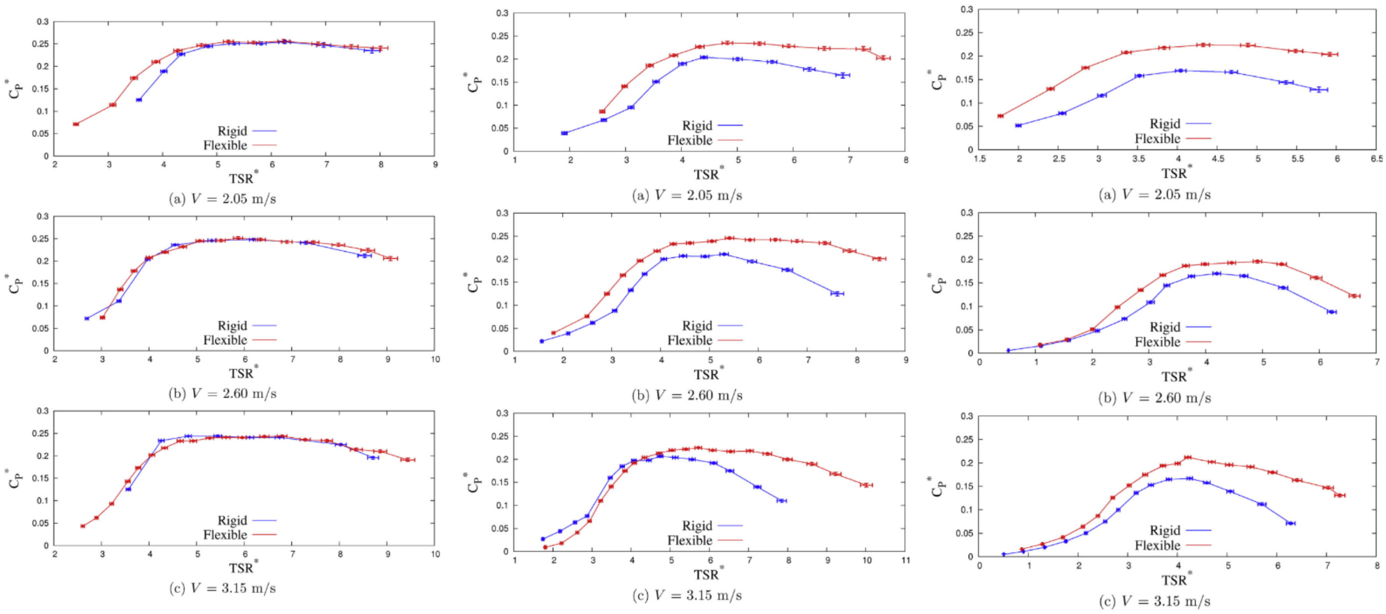

Figure 3.2 – The result of experiment

(resource: 《Performance analysis of a small wind turbine equipped with flexible blades》)

Varying the blade pitch angles (b) between 3°,6°and 9° resulted in drastically different efficiency curves as is expected with a change in geometry. The case where b ¼ 3+ and V ¼ 2.05 m/s resulted in the highest maximum corrected power coefficient, $C^*_{p,max}$ for both rigid and flexible rotors. For these cases, $C^*_{p,max}$ for the rigid and flexible rotors was 0.254 and 0.256, respectively.

There was no stark differences in performance when b ¼ 3+ across all wind speeds. As blade pitch angle was increased, performance of the rigid rotor diminished far more than that of the flexible rotor. In one such case, where b ¼ 9+ and V ¼ 2.05 m/s, $C^*_{p,max}$ was 0.169 for the rigid rotor and 0.224 for the flexible rotor, reflecting a 32.6% increase in maximum corrected power coefficient for the morphing bladed design.[5]

4. Conclusions

We can know that by employing the flexible rotor, the operating envelope and efficiency are effectively enhanced, and the projected impact of converting more wind energy is converted within a range of operations through the analysis of experimental data. The trailing edge of the flexible blade is displaced. The performance decline can be minimized by blade deformation when the circumstances deviate more from the ideal point, and the difference between the flexible and stiff rotors becomes more obvious.

As a result, the deformed blade design avoids performance deterioration caused by blade deflection due to passive deflection, allowing for more torque and power conversion than rigid blades.

From this experiment we can see that it may be worthwhile to make flexibility a design parameter for future turbine development. It is hoped that in the future, with further research on this topic, it will be possible to change the impact of flexible blades on improving turbine blade design, thereby improving turbine operation efficiency and energy conversion efficiency.

5. References

[1] Giovanni Bracco, « Wind Energy Introduction » [Lecture]. Available: https://didattica.polito.it/pls/portal30/sviluppo.pagina_corso.main

[2/3/4/5] David W. MacPhee , Asfaw Beyene, « Performance analysis of a small wind turbine equipped with flexible blades » [Online]. Available: https://www-sciencedirect com.ezproxy.biblio.polito.it/science/article/pii/S0960148118309649.