SOME RECENT ADVANCEMENTS IN WIND ENERGY TECHNOLOGIES

INTRODUCTION:

Wind power has been present for almost as long as humanity has existed. As early as 5000 BC, ancient Egyptians harnessed the winds to propel their vessels across the Nile[1]. The concept of wind power is so timeless and prevalent that it requires almost no introduction. However, it can still improve. As time progressed, wind power became much more than a propulsion mechanism. In the Eastern hemisphere, incarnations of wind power saw use in food production1, irrigation control1, and saw mills1, typically encapsulated in the familiar windmill shape as shown in Figure 1. And in the advent of electricity, it was only a matter of time before the wind would adapt for use in the electrical age. This adaptation manifested as wind turbines, which function like the windmills of the previous era by repurposing the wind to push blades and power an attached generator[2].

Wind turbines come in all shapes and sizes[2] for all purposes, but they are far from the only form of power. While one of the oldest sources of power, it has been completely eclipsed by fossil fuels in prominence and ubiquity. The efficacy of fossil fuels, however, was tempered by the deadly carbon emissions from their use. Recently, global organizations have lobbied in favor of curbing carbon emissions and pursuing cleaner energy alternatives in favor of reducing the effects of global warming and preserving the planet for future generations. Thus, wind power was once again at the forefront, and in recent years, that attention has resulted in numerous groundbreaking innovations in the field of wind power. This article catalogs several innovations in wind power across the past 3-4 years, noting the area of wind power it influences and its positive implications for future studies.

Wind Turbine Blades:

As wind turbines are ubiquitous, many have sought to innovate on the traditional wind turbine design, as shown in Figure 2. As a general trend, these wind turbines have grown larger to better harness and withstand stronger wind currents at higher altitudes[3]. Consequently, wind turbines have become harder to manufacture and maintain, owing to the steeper production and transport costs of the parts[4], which leads to the construction of a single commercial turbine costing upwards of $4 million[5], far beyond the grasp of many prospective buyers. Furthermore, wind turbine blades have an average lifespan of 20-25 years[6] before they must be replaced, further compounding maintenance fees. The steep costs of turbine construction, transportation, and maintenance left wind turbines relatively expensive compared to other energy sources.

To combat this issue, researchers at the U.S National Renewable Energy Laboratory (NREL) 2020 posted a study detailing the practicality and reliability of an alternative wind turbine blade that utilized a thermoplastic resin composite rather than the traditional thermoset composition[7]. Because of its use of thermoplastics, the turbine blades could be created on-site[8], drastically reducing the cost of production and transportation in one fell swoop. Furthermore, the turbine blades were very malleable through heat and could be melted down into resin, further cheapening the repair process and allowing the blades to be recycled at the end of their lifespan.

Figure 1,2: A traditional Dutch windmill and a modern wind turbine Source https://www.eia/gov/energyexplained/wind/history-of-wind-power.php

Finally, in the testing process, the group revealed that the thermoplastic blades behaved similarly to the standard blades while exhibiting greater structural damping, meaning that the thermoplastic blades take a far shorter time to return to their original displacement. If thermoplastic blades were cleared for mass production, wind turbine blades could be roughly 5 percent cheaper to produce and maintain8 while performing more reliably due to the malleable and adaptable thermoplastic material. Thus, thermoplastic blades could dramatically increase the sustainability and cost-effectiveness of wind turbine blades.

Vertical Axis Wind Turbines:

Vertical Axis Wind Turbines (VAWTs) date back to the 9th century[9], relying on aerodynamic drag over lift for their propulsion mechanisms. Their design has also carried to modern energy systems, though lack of long-term interest[8] for VAWTs means that they will remain in the shadow of horizontal axis wind turbines. However, they still have strong merits. Due to their vertical design, they are much more compact than horizontal turbines and thus can be placed in much denser arrays that can produce up to 10 times more power per unit area than horizontal turbines[10]. Additionally, their design makes them more suited toward hurricane-force winds than their horizontal counterparts[11]. Thus, VAWTs are prime for wind turbine farms set offshore, and one company has taken note of that.

Swedish turbine company SeaTwirl is a company that exclusively produces offshore vertical wind turbines, benefitting from the stronger winds in the ocean and the turbine's greater structural strength[11]. Specific to this company's turbines is a buoy and keel structure attached to the turbine tower, which allows the turbine to turn with the winds and maintain its stability through them. Furthermore, as the company employs several mooring lines in each structure, SeaTwirl turbines can be anchored farther than the traditional depth of 50-60 meters[11] that offshore turbines are generally limited to. Thus, clients can create wind farms in consistently turbulent areas where other offshore turbines can't anchor.

In their desire to further optimize the energy gain of their farms, SeaTwirl commissioned a researcher from the University of Manchester to verify the energy generation of several different configurations of offshore wind farms through wake modelling[12]. Each layout consisted of five rows of five turbines per row, differing by the distance between the turbines. Additionally, three horizontal wind turbine farm layouts were directly compared to their vertical counterparts. Table 1 details the layouts of the farms, and the variations between the layouts are detailed below. As expected in the test, the three vertical wind turbine farms outperformed their opponents due to their increased wake recovery[12]. Additionally, the study found that more slender VAWTs generate more energy and recover faster, as thinner rotors would further reduce wake interactions and increase energy gain. Thus, if vertical axis wind farms became the norm for offshore wind farms, power generation would increase dramatically due to the increased competence of VAWTs and this unique mooring system. Furthermore, if further research is conducted in this field, slimmer VAWT rotors may become the norm for offshore wind farms, and offshore farm energy generation will increase furtherized.

FARM LAYOUT	S_x/D_0	S_y/D_0	$S_{eq} = (S_xS_y)^{0.5}/D_0$
1	5	5	5.00
2	5	3	3.87
3	5	2	3.16
4	8	8	8.00
5	8	5	6.32
6	8	3	4.90
7	12	8	9.80
8	12	5	7.75
9	12	3	6.00

Table 1: The layouts of each analyzed wind farm. Sx = Streamwise spacing between turbines, Sy = Spanwise spacing between turbines. Source: https://seatwirl.com/content/uploads/SeaTwirl-wind-farm-layout-design_v5_FINAL.pdf

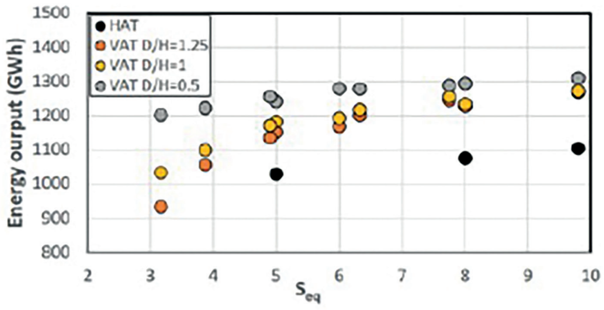

Figure 3: Energy output in GWh estimated tob e produced from offshore wind turbines using HWATs or VWATs with various configurations. Source: https://seatwirl.com/content/uploads/SeaTwirl-wind-farm-layout-design_v5_FINAL.pdf

Bladeless Turbines:

In addition to the existing models, a new wind turbine design uses aerodynamic principles to generate electricity from wind flow. While traditional wind turbine blades are efficient, they are loud and large. Their obstructive size and constant noise pollution make them near impossible to construct within cities. This is where bladeless wind turbines come in. As the name implies, these turbines do not possess blades, and all models utilize certain aerodynamic principles to manipulate the wind and generate electricity[13]. Due to this, bladeless turbines are far more compact and much quieter, allowing construction in densely populated areas. In this vein, we will focus on Aeromine Technologies, a startup company that proposes a remarkably compact bladeless turbine design[14]. Intended for rooftops, the device uses two vertical airfoils that generate a field of low pressure between them as air flows through the foils. This pulls the air through a cylindrical tower past a turbine at the base, generating electricity.

In contrast to its bladed counterparts, this design is far simpler, with fewer moving parts allowing for simpler installation and maintenance[14]. On top of this, the company claims that one Aeromine device generates as much electrical energy as 16 solar panels while taking up a fraction of the space and can function at wind speeds as low as five mph[14]. However, while the device cannot power a single building alone, it is meant to be a part of a combination of distributed energy sources, functioning with a conjunction of solar and other energy sources to power the grid.

To determine the efficacy of this technology, several researchers at Texas Tech University conducted a study examining the performance of an Aeromine device under a series of wind streams ranging from 5 to 15 m/s[15]. A 0.5 m chord pair of Aeromine foils were used along with the university's wind tunnel to simulate freestream velocities, and a choke was placed to simulate the device's optimum conditions at the same load as a standard turbine generator. Then, the mechanical efficiency of the system was calculated by comparing the power generated and the maximum possible power of the system. Following the experiment, the Aeromine device's peak measured efficiency was calculated to be around 18%. This equates to roughly ⅓ of the Betz limit, the theoretical maximum efficiency of a wind turbine measuring around 59.3% of the kinetic energy from wind[16].

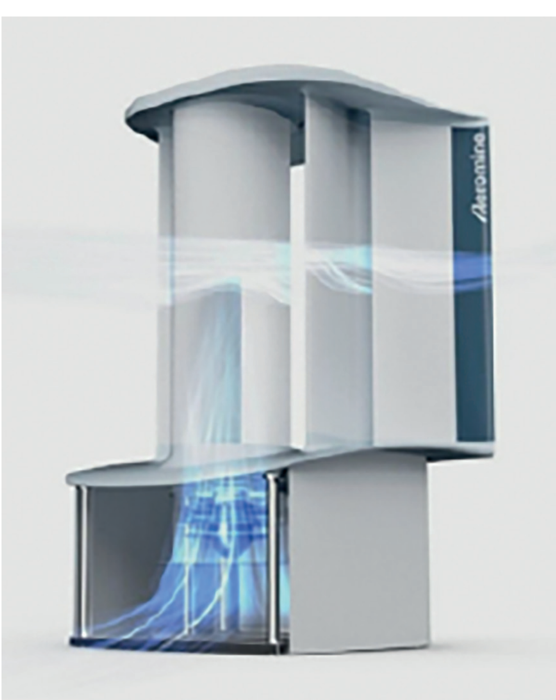

Figure 4: The diagram of an Aeromine device. Source: https://eepower.com/market-insights/aeromine-an-elegantly-simple-rooftop-wind-energy-solution/

Standard turbines are more efficient than the measured results, equating to around 35-45% efficiency[16]. However, despite almost being half as efficient as a standard turbine, the device is also drastically smaller, measuring around 1.22 meters compared to a standard turbine which can be hundreds of times larger[3]. At that size, many more Aeromine devices can be arranged in the same amount of space that a traditional turbine occupies, generating much more energy while producing far less noise. While more experiments can further optimize energy output, Aeromine has already released a commercial model. If these models catch on, rooftop bladeless turbines may become commonplace, contributing much more electricity to the grid without requiring much adaptation for the existing electric grid.

Offshore Multi-Turbine Platforms:

Norwegian company Wind Catching Systems has designed a unique offshore wind farm that aims to further reduce construction and maintenance costs for offshore farms[17]. Rather than a traditional offshore wind farm, typically a horizontal grid of individual turbines, the company has designed a single vertical grid-like frame consisting of 126 rotors to generate a combined 126 MW of power[18]. As a traditional wind turbine has an output of roughly 8-15 MW[19], the company claims that just five of these structures could equal the power generated by 25 conventional offshore turbines while occupying a fraction of the space[17].

This structure, nicknamed the Windcatcher[18], is enormous, spanning over 300 meters in length and height. But for its size, the rotors are comparatively smaller than those of traditional offshore wind farms, measuring 15 meters long compared to the standard 115-meter-long blades[20]. The smaller blades are intentional, however, as smaller blades are lightweight, perform more rotations per minute, and harness faster winds. Additionally, by placing the rotors close to each other, the company anticipates that the turbulence created by one rotor can be harnessed by the surrounding rotors, thus optimizing the performance of all rotors in sequence[20].

Finally, by using readily available rotors and merging numerous rotors onto a single platform, the company hopes to reduce the price of energy from offshore turbines[20]. Due to the incredibly steep cost associated with offshore farms, offshore energy is far more expensive than other alternative energy sources[20]. The construction of the Windcatcher is an attempt to remedy this, as it combines readily available materials and techniques into a single framework to simplify the cost of repairs. From this framework, the company reports that the Windcatchers will cost less to produce than individual offshore turbines while generating more electricity and possessing a longer lifespan[20]. While still in development, the structure has drawn the attention and support of Norway and its government. Enova, an investment company owned by the Ministry of Climate and the Environment, has recently awarded Wind Catching Systems a grant of $2.1 million towards the design, construction, and testing of a scaled-down version of the Windcatcher on the West Coast of Norway[18]. While the structure is quite bizarre, if the company produces a working model, the future of offshore wind farms may be permanently affected by the arrival of floating multi-turbine platforms.

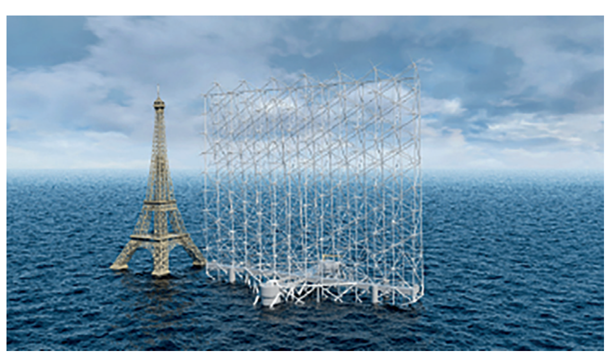

Figure 5: An image of a floating Windcatcher (304.8 m) next to the Eiffel Tower (300 m) for scale. Source: https://windcatching.com/

Conclusion:

To conclude, the field of wind power is ever-prevalent and ever-growing, from innovations to the blades to offshore developments that promise to drive offshore electricity prices down to smaller bladeless turbines that assist in providing alternative electricity to cities everywhere while remaining silent but effective. Still, many more developments are underway to make wind turbines more reliable and efficient. In particular, while the technology is still quite finicky, the growth of wind turbine sensors promises to be a significant upcoming development, as the ability to sense defects and damages within turbines can revolutionize turbine maintenance[21]. Wind power will continue to be a very innovative field. Wind turbines will grow larger, electricity will get cheaper, and alternative energy will prevail at the end of the day.

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Authors

Dr. Raj Shah is a distinguished professional with a wealth of expertise in the petroleum and alternative energy field. Currently serving as the Director at Koehler Instrument Company in New York, he has dedicated the past 28 years to his current company. Dr. Shah's exceptional contributions to the industry have been recognized by his esteemed peers, resulting in his election as a Fellow by prestigious organizations such as IChemE, CMI, STLE, AIC, NLGI, INSTMC, Institute of Physics, The Energy Institute, and The Royal Society of Chemistry.

In addition to his esteemed reputation, Dr. Shah has been honoured with the ASTM Eagle award. He recently coedited the highly acclaimed bestseller, "Fuels and Lubricants Handbook," a publication that has garnered widespread acclaim in the industry. Detailed information about this book can be accessed through the following link: ASTM's Long-Awaited Fuels and Lubricants Handbook 2nd Edition Now Available (https://bit.ly/3u2e6GY)

Dr. Shah's academic achievements are equally impressive, having earned his doctorate in Chemical Engineering from The Pennsylvania State University. He holds the distinguished title of Fellow from The Chartered Management Institute, London, and boasts credentials as a Chartered Scientist with the Science Council, a Chartered Petroleum Engineer with the Energy Institute, and a Chartered Engineer with the Engineering Council, UK.

Acknowledging his exceptional accomplishments, Dr. Shah has been bestowed with the honourific of "Eminent engineer" by Tau Beta Pi, the largest engineering society in the USA. He serves on the Advisory Board of Directors at esteemed institutions such as Farmingdale University (Mechanical Technology), Auburn University (Tribology), School of Engineering design and Innovation at the Pennsylvania State University , State College, PA, SUNY Farmingdale (Engineering Management), and State University of NY, Stony Brook (Chemical Engineering/Material Science and Engineering).

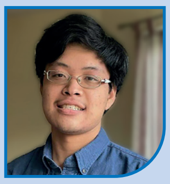
Furthermore, Dr. Shah holds the position of Adjunct Professor at the State University of New York, Stony Brook, in the Department of Material Science and Chemical Engineering. With an impressive portfolio of approximately 600 publications in the field, he remains actively engaged in the energy industry for over three decades.

For additional information on Dr. Raj Shah, please visit his profile at https://bit.ly/3QvfaLX

For any inquiries, Dr. Shah can be contacted at rshah@koehlerinstrument.com.

Mr. Beau Eng is a student of Chemical Engineering at State University of NY, Stony Brook. He is a current intern at Koehler Instrument Company active in the field of alternative energy technologies .

Ms. Mrinaleni Das is part of a thriving internship program at Koehler Instrument company in Holtsville, and students of Chemical Engineering at Stony Brook university, Long island, where Dr. Shah is the current chair of the external advisory board of directors


Beau Eng


Mrinaleni Das

Author Contact Details

Dr. Raj Shah, Koehler Instrument Company • Holtsvile, NY11742 USA • Email: rshah@koehlerinstrument.com • Web: www.koehlerinstrument.com