SECTION 14. WIND POWER

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14.1 Analysis of «horizantal» wind turbines from different aspects

Abstract

The contribution of wind turbines in energy production has increased over the years and has reached an irreplaceable point. The environment that a wind turbine requires to get a lot of energy is more of an offshore environment. Since the amount of energy received by the wind turbine depends on the wind pattern, it is possible to conclude that the offshore environment is sufficient to provide turbine with this wind pattern. Since the efficiency of turbines depends on various parameters, they can increase and decrease, so these parameters must be continuously monitored. Determining, evaluating and mitigating external impacts on offshore turbines can extend the likehood of turbines. A number of successful offshore projects can be listed, which greatly contribute to the implementation of future projects in the offshore environment. The field of application of wind turbines is more onshore than offshore. In this regard, it may be possible to apply its field of application to marine vehicles as well. This research paper will explain the potential of wind turbines, their importance, external influences on it, its types, implemented projects, its advantages and disadvantages.

Keywords

Wind Energy, Offshore Wind Farms, Wind Turbine Efficiency, Wind Speed, Blade Friction, Turbine Layout, Environmental impact, Wind Farm Planning, Wind Farm Planning

14.1.1 Introduction

These days, as the world's need for energy increases, it is important to increase the scope of ways to obtain this energy. There are various sources of electricity that we use, various techniques, and different ways of applying these techniques. Just as the types of energy sources have different efficiency, the environment in which we obtain these energy sources also plays a large role as a factor that directly affects efficiency.

Wind energy, which is a type of renewable energy, is one of the most advanced alternative energy sources, either from the economic point of view, from the point of view of efficiency, also view of the cleanliness. The interest of energy companies in this type of energy sources, as well as their efforts to increase their field of application, and the support allocated to conveying this interest to the society, have developed the application of this field and aroused new interests. The creation of wind both naturally and artificially,has made it possible to special the installation of wind turbines in the mountains, fields, oceans, sea, various parts of the city, transport vehicles and etc. The environment in which we use wind turbines demands from us which type of turbine we will use according to the requirements of this environment. The primary considerations influencing the placement of turbines typically include maximizing energy output, visual impact, noise levels, wind speed, and the loads imposed on the turbines. Wind energy represents a substantial opportunity for reducing greenhouse gas (GHG) emissions in both the short-term (by 2020) and the long-term (by 2050). Numerous wind energy technologies cater to various applications, but the predominant approach for climate change mitigation involves generating electricity through larger grid-connected wind turbines, which can be deployed either onshore or offshore. Developers of wind farms have the option of choosing between onshore and offshore locations. Offshore wind farms are often favored over their onshore counterparts for several reasons, including their higher wind potential characterized by stronger and more consistent wind profiles.

The use of wind energy in the marine environment has existed since ancient times, so it is possible to assume that it was the first alternative energy source used by ancient people. For the first time, wind energy was used to move ships from one point to another. As far back as 5,000 BC, wind energy found practical applications as it was harnessed to propel boats on the Nile River. By 200 BC, basic wind-driven water pumps were already in use in China, and windmills featuring blades made from woven reeds were employed to grind grain in regions like Persia and the Middle East. While harnessing wind energy in a marine environment can be highly effective and efficient, the installation of turbines can pose a variety of challenges. The development, production, and operation of offshore wind facilities present distinct challenges, encompassing issues such as corrosion, fatigue, erosion, lightning strikes, and biofouling. As the dependence on offshore wind energy continues to expand, it becomes progressively more vital to tackle these challenges and ensure the ongoing operational efficiency of offshore wind turbines. Otherwise, wind turbines in marine environments, particularly offshore, benefit from consistent and stronger winds, resulting in higher energy production efficiency. The reduced wake effects between turbines and access to high-voltage grids near population centers contribute to improved overall efficiency. Larger and more powerful offshore turbines further enhance energy capture, making offshore wind energy an attractive and efficient renewable energy source. It is essential to expand the range of wind turbine installations in marine environments, including both stationary configurations like Offshore Wind Farms (OWF) and dynamic setups such as those installed on ships. A primary motivation for enhancing wind turbines mounted on ships is the consistent airflow they encounter. When ships are in motion, irrespective of the wind's direction, the aerodynamic force generated by the ship allows for the continuous rotation of the turbine.

Offshore wind farms are typically classified into three main categories: Fixed-Bottom, Floating, and hybrid systems. Fixed-Bottom wind farms, the most common type, secure turbines to the seabed using steel or concrete foundations. In contrast, Floating wind farms employ buoyant platforms tethered to the seabed with cables or chains, adapting to wave motion for stability, while hybrid systems combine aspects of both technologies for optimal performance.The deployment of vertical axis wind turbines (VAWTs) in offshore environments presents specific challenges, notably their lower energy capture efficiency compared to horizontal axis turbines (HAWTs), which are the more established choice in offshore applications. Maintenance can be intricate due to the complexity of VAWT mechanical systems, and scaling them up to match the power output of larger HAWTs poses challenges. Furthermore, engineering stable and cost-effective floating platforms for VAWTs in deep waters remains a significant technical and economic concern.However, VAWTs demonstrate distinct advantages in dynamic settings, such as marine environments. In maritime contexts, VAWTs often outperform HAWTs, as they can capture wind from any direction, adapting to changing wind conditions at sea. Their compact design, stability in dynamic maritime conditions, and ease of maintenance make them a favorable choice for ship-mounted wind energy generation. This research paper will explore the performance of both wind turbine types, analyze their constraints,investigate emerging technological applications, and present my unique perspective on their potential applications in innovative technologies.

14.1.2 Methodology

14.1.2.1 Overview of measurement:

Wind turbine deployment in the marine environment necessitates strict conformity to existing criteria as well as fabrication influenced by empirical data. Because turbine performance varies with environmental conditions, turbine design, external forces, and ongoing evaluation, freshly erected wind turbines are expected to lose performance as time goes on. Offshore wind farms reap the rewards of increased constancy in wind output and availability, resulting in more predictable and efficient supply of electricity. Let's first examine the factors that enhance the efficiency of wind turbines and those that diminish their effectiveness.

14.1.2.2 Factors that enhance the efficiency

The efficiency of wind turbines can change, taking into account several factors. Some of these factors can change taking into account optimal regimes, others can remain as a negative factor in wind turbine optimization process.

14.1.2.2.1 Wind speed and length of wind season

The amount of power generated by a wind turbine is primarily determined by the wind speed. Wind power density is directly proportional to the cube of wind speed. Assuming all other factors remain constant, a 10% rise in wind speed leads to a 33% increase in wind power output.

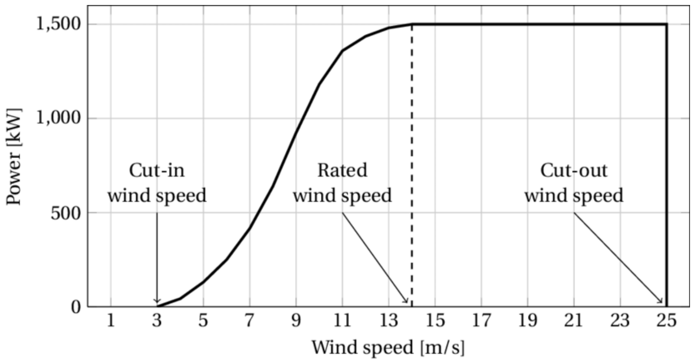

Figure 1. An illustration of a 1500 kW wind turbine's power graph

Wind turbines are carefully engineered to operate effectively within a specific range of wind speeds, defined by the cut-in speed and cut-out speed. The cut-in speed represents the minimum wind velocity at which the turbine can begin generating power, with power output increasing exponentially with wind speed between the cut-in and rated speeds. However, beyond the rated speed, the cubic relationship levels off. The cut-out speed signifies the point at which the turbine must be shut down to prevent equipment damage. These crucial parameters are determined based on the turbine's design and size during the pre-construction planning phase.

14.1.2.2.2 Diameter of the rotating blades

Enlarging rotor diameters empowers wind turbines to cover a wider expanse, harness more wind, and generate increased electricity. Longer blades on a turbine enable it to efficiently capture a greater portion of the available wind, even in regions characterized by lower wind speeds. This capability to harness more wind at lower wind speeds has the potential to expand the range of suitable locations for nationwide wind energy development.

The most comprehensive formula for calculating the power generated by a wind turbine (measured in Watts) is:

$$P = 0.5\times Cp \times\rho\times \pi\times R^2 \times V^3 \qquad (1)$$

Cp is the coefficient of performance (efficiency factor, in percent), ρ is air density (in kg/m3), R is the blade length (in meters) and V is the wind speed (in meters per second).

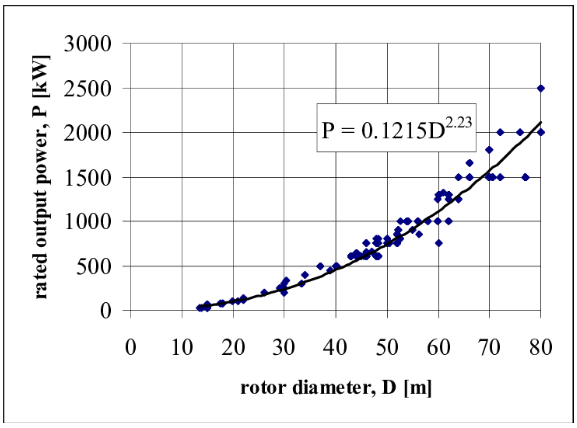

Figure 2. The correlation between the diameter of the rotor and the generated power output in a wind turbine

14.1.2.2.3 The efficiency of wind turbine components

The suboptimal performance of individual wind turbine components has a direct impact on the overall system power output. System efficiency is expected to improve through advancements in blade design, gearbox efficiency, and generator technology. To assess these improvements, degradation models were developed, focusing on gearbox degradation levels, a critical component of wind turbines. These models utilize an artificial neural network (ANN) with a unique architecture to monitor deviations in wind power curves, using the cumulative summation (CUSUM) change detection algorithm to pinpoint changes in gearbox efficiency based on predicted power residuals. In this study, we explore three distinct operating modes for the WT "DeWindD6—1250 kW," each associated with varying levels of gearbox efficiency degradation. This degradation in gearbox efficiency can arise from factors such as inadequate lubrication, elevated temperatures, and mechanical losses, including torque losses due to friction between the High-Speed Shaft (HSS) and Low-Speed Shaft (LSS).

$$HSS(torque) = \frac{LSS(torque) \cdot efficiency}{gearbox\,ratio} \quad (2)$$

$$LSS(torque) = \frac{HSS(torque) \cdot efficiency}{gearbox\,ratio} \quad (3)$$

Sustained control and monitoring of the yaw controller, generator, and shafts are essential for achieving the maximum potential output from the generator system.

14.1.2.2.4 Pitch control

The pitch of a turbine blade refers to the angle of its leading edge facing the wind. The degree of pitch plays a crucial role in the performance of the turbine, as excessive pitch can lead to insufficient airflow over the blade (when too narrow) or excessive drag (when too wide). To optimize power output and prevent the turbine from exceeding its maximum rotational speed, wind turbines adjust their blades by rotating them. This rotation ensures that the blades harness the appropriate portion of the available wind energy. To manage the pitch angle of wind turbine blades during power outages, engineers have traditionally relied on motors powered by lead-acid batteries, which typically last between three to five years and can be challenging to monitor.

A typical pitch controller, which may have been in operation for five years or more, can contain a multitude of components, including thousands of wires and termination points, introducing numerous potential points of failure. Pitch System 3 addresses this by reducing the conventional part count by 60% and extending the intervals between scheduled maintenance. This innovative technology and design approach applied to pitch controllers could soon find applications in more conventional power generation facilities.

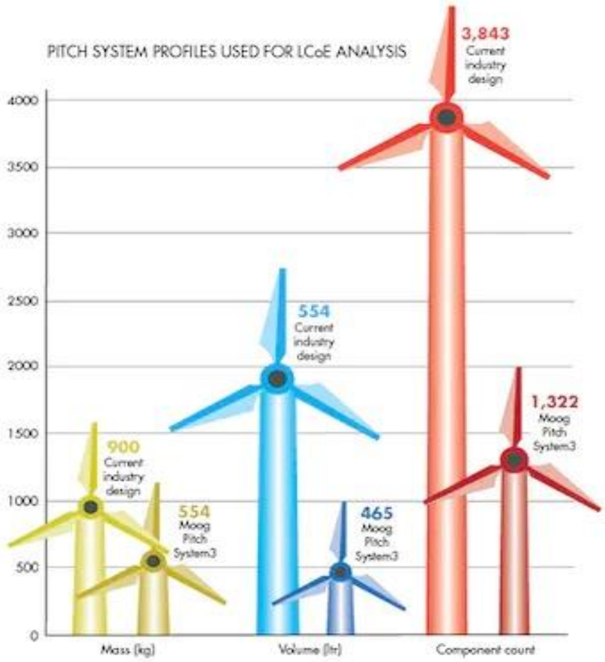

Figure 3. Pitch system profiles LCoE Analysis

14.1.2.2.5 Arrangement of the turbines in the farm

The engineering planning process for a wind farm typically encompasses essential decision-making aspects, which may include (but are not restricted to) the following:

l. the layout of the turbines in the wind farm,

ll. the number of wind turbines to be installed, and

Ill. the types of wind turbines to be installed.

The overall power output of a wind farm is often notably lower than what would be expected from multiplying "the power generated by an individual turbine" by "the total number of identical turbines (N)" in the farm. This reduced efficiency can be attributed to energy losses caused by wake effects, specifically, the shadowing impact of one wind turbine on others situated downstream from it. As it appears, the solution doesn't lie within technological advancements but rather resides in the realm of atmospheric science. Our investigation, conducted roughly a decade ago, centered on understanding the limitations of harnessing wind energy to its fullest potential. The central idea revolves around the impact of turbines on the atmosphere; they extract the kinetic energy necessary for them to operate. The total power output of a wind farm results from the cumulative contributions of individual turbines, with each contribution linked to wind speed profiles applied to respective turbines. Consequently, calculating parameters such as **dti** and **dsi**, as outlined below, becomes crucial:

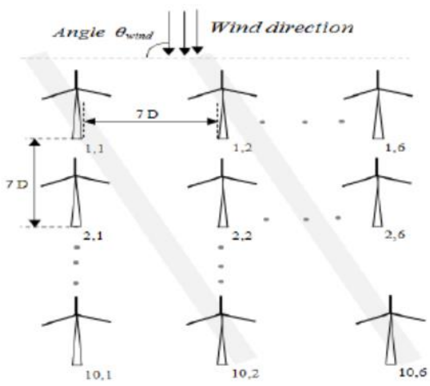

Figure 4. Optimum tower spacing in wind farms in flat terrain

$$dt_i = \frac{7\,D}{V_{1\,mean}} i \tag{4}$$

$$ds_i = b_i \tag{5}$$

Where, $V_{1\,mean}$ is the average value of wind speed for first linee (i=1), D represents the wind turbine diametr, and b is between 2% and 4%. The estimation of the wind speed profile for each wind turbine can be conducted using the following equation:

$$V_i = V_1\left(t - \frac{7\,D}{V_{1\,mean}} i\right)(1 - b_i) \quad (6)$$

The aggregate power output generated by the wind farm is:

$$P_p = 6\Sigma_{i=1}^{10} P_i \quad (7)$$

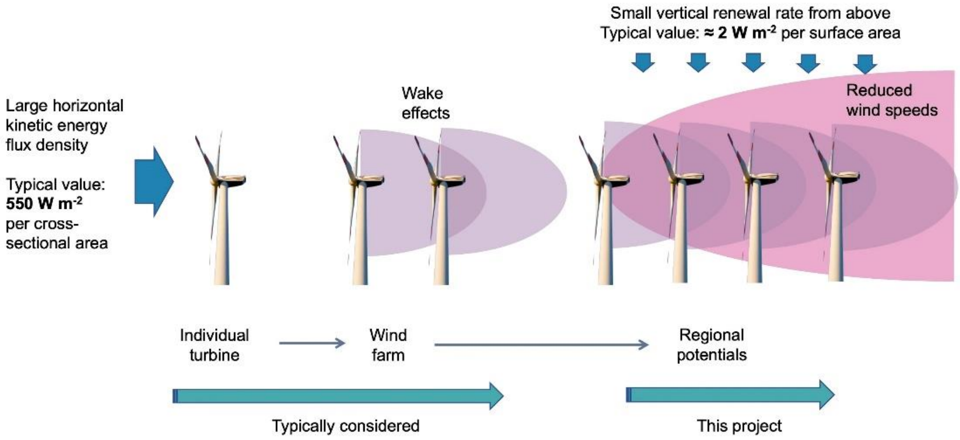

Figure 5. As wind farms are bigger, they have a bigger effect on slowing down the local wind, which lowers the efficiency of the turbines.

Turbines leave behind a reduced amount of energy because the atmosphere's capacity to generate and transport kinetic energy is thermodynamically limited to a relatively low power and renewal rate. This effect is not significant for a single turbine, but as the number of turbines under consideration increases, it becomes increasingly pronounced, as demonstrated here. It's worth noting that this phenomenon extends beyond the wake effects observed behind individual turbines, which are well-understood, modeled, and factored in (refer to Figure).

14.1.2.3 Factors that diminish the efficiency

The principle of mass conservation dictates that the volume of air entering and exiting a turbine must be in equilibrium. Consequently, Betz's law establishes the maximum attainable wind power extraction by a wind turbine at 16/27 (approximately 59.3%) of the rate at which the kinetic energy of the incoming air is delivered to the turbine. If the effective area of the disk is A, and the wind velocity v, the maximum theoretical power output P is:

$$P=\frac{\rho\times v\times A^{3}\times 8}{27} \tag{8}$$

- Power (P) is typically measured in Watts (W).
- The density of the air (ρ, Greek letter "rho") is represented in units of kilograms per cubic meter (kg/m^3).
- The cross-sectional area of the wind (A) is measured in square meters (m^2).
- The velocity of the wind (v) is expressed in meters per second (m/s).

It is undeniable that the power increases by a factor of 8 when the velocity doubles, and by a factor of 27 when the velocity triples. Due to the velocity's cubing, 23 = 8 and 33 = 27, respectively. The cube of the wind velocity has a significant impact on the power output in wind turbines.

Wind Speed and Corresponding Power Output (kW)

wind speed (m/s)	1	2	3	4	5	6	7	8	9	10	11	12
power output (kW)	-0.5	-0.5	1.2	7.2	14.5	24.7	37.9	58.7	74.8	85.1	90.2	94.7

Wind Speed and Corresponding Power Output (kW)

wind speed (m/s)	13	14	15	16	17	18	19	20	21	22	23	24	25
power output (kW)	95.3	95.1	94.2	92.9	91.2	88.9	87.1	84.1	81.3	78.6	75.1	74.3	71.7

14.1.2.3.1 Aerodynamic drug

Both aircraft engineers, responsible for crafting airplane wings and propellers, and wind turbine engineers, who specialize in rotor blade design, share a common concern for aerodynamic drag. The concept of drag remains a critical consideration whenever an object moves swiftly through the air. In the case of aircraft, achieving optimal fuel efficiency is paramount, while for wind turbine rotor blades, maintaining high tip speeds is essential for efficient operation.

Figure 6. A parachute's design exhibits a notably elevated drag coefficient of 1.42

The drag coefficient, denoted as CD, represents the drag force per square meter of the object's frontal area. It's important to note that drag escalates with the square of the wind speed. In contemporary wind turbines, the rotor blades operate at significantly high tip speeds. The tip-speed ratio, referred to as λ or TSR for wind turbines, is the ratio between the tangential speed and the linear wind speed.

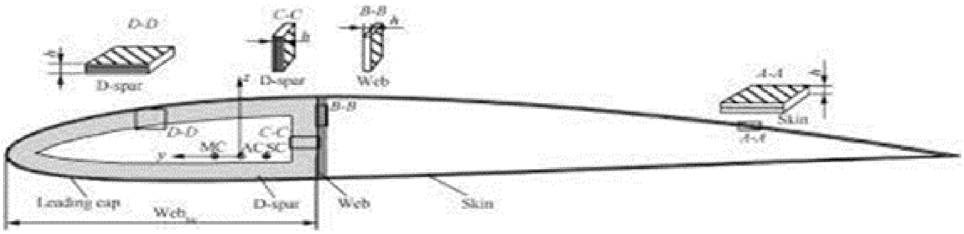

Figure 7. Airfoil shaped rotor blades(Cd=.045)

Increased tip speeds lead to elevated noise levels and necessitate sturdier blades to withstand greater centrifugal forces. To achieve optimal efficiency, it becomes crucial to employ airfoil-shaped rotor blades with exceptionally high lift-to-drag ratios, especially in offshore environments. Additionally, it's important to note that both lift and drag are directly proportional to the air's density. Colder air, therefore, results in more significant drag compared to warmer air. This enables us to consolidate all the various effects, whether straightforward or intricate, into a unified equation. Known as the drag equation, it states that drag D is equal to the drag coefficient Cd times the density ρ times half of the velocity squared V^2 times the reference area A.

$$D = Cd \times A \times 0.5 \times \rho \times V^2 \tag{9}$$

14.1.2.3.2 Blade friction

Blade friction within a wind turbine pertains to the obstruction faced by the turbine blades during their rotation in the air. This phenomenon represents a type of aerodynamic drag, which has the potential to diminish the turbine's overall efficiency. Blade friction accomplishes this by transforming a portion of the wind's kinetic energy into heat, ultimately diminishing the power output of the turbine. The frictional torque experienced by a bearing can be categorized into two components: one that is independent of the load and another that is contingent on the load. The load-independent portion T_0 takes into account an empirical value f_0 and the bearing diameter D_M ,
The model does not incorporate speed dependence for low rotational speeds, as is commonly observed in pitch bearing applications.

$$T_0 = f_0 \times 10^{-7} \times 160 \times D_M^3 \; ; \; if \; (v \times n) < 2000 \frac{m^2}{60 \times s^2} \tag{10}$$

The load-dependent part T_1 depends on another empirical value f_1, the bearing diameter D_M and the equivalent load P_1

$$T_1 = f_1 \times P_1 \times D_M \tag{11}$$

Opting for suitable lubricants appears to be a viable strategy for mitigating wear in turbine bearings. The conditions encountered in blade bearings pose significant challenges for the effective use of grease lubricants.

	Thickener	Base oil	NLGI	Viscosity
Grease 1	Lithium complex	Mineral / Synthetic	1	130 mm/s²
Grease 2	Lithium	Synthetic	2	50 mm/s²
Grease 3	Lithium	Ester	1-2	320 mm/s²

Figure 8. measured lubricants with grease characteristics

14.1.2.3.3 Air Density

Power output hinges on local air density, which varies with altitude, pressure, and temperature. Near coastal areas, wind speeds are elevated due to temperature disparities between land and the ocean, with higher air pressure above the sea drawing air from the coast. Notably, the difference in heating rates between land and water results in warmer air rising over land, leading to lower surface pressure, while colder air over the ocean creates higher surface pressure; denser air, in turn, exerts greater pressure on the turbine rotors, yielding higher power output.

Air density is typically considered as 1.225 kg/m^3, The reference air density is typically established at sea level with a temperature of 15 degrees Celsius. It’s crucial to consider that wind turbines can yield significantly more power in colder conditions due to the higher air density, in contrast to warmer seasons. In power curve analysis, a standardized air density value is utilized to represent the average air temperature at sea level, necessitating the application of air density correction in pitch-regulated wind turbines, wherein a corrected wind speed (Vo) is calculated using the provided equations.

$$\rho = 1.225\left[\frac{288.15}{T}\right]\left[\frac{B}{1013.3}\right] \tag{12}$$

And,

$$V_c = V_m\left[\frac{\rho}{1.225}\right]^{\frac{1}{3}} \tag{13}$$

where Vc and V_M are the corrected wind speed, measured in meters per second, and the adjusted air density are computed using Equation (x), where ‘B’ represents atmospheric pressure in mbar, and ‘T’ corresponds to temperature in Kelvin. These values are derived from 10-minute average data obtained from SCADA (Supervisory Control And Data Acquisition) systems, which are a combination of software and hardware components used by industrial organizations to oversee, remotely control, collect real-time data, and interact with various devices like sensors, valves, pumps, and motors. The corrected wind speed is then (V_c) the power curve is typically calculated using the corrected wind speed derived from Equation 3, often through a binning process.

14.1.2.3.4 Corrosion of OWTs

Conventional monopile offshore wind turbines (OWTs) typically feature diameters ranging from 3 to 8 meters and are economically viable for water depths spanning 20 to 40 meters. The ongoing advancement in monopile technology involves the development of larger diameters and lengths. In contrast, the TetraSpar floater is designed for installation at water depths ranging from 10 meters to as deep as 1000 meters. Corrosion in wind turbines exposed to water is an inevitable process, with the extent of corrosion increasing notably in greater water depths. Unlike the approach for critical rotating.

components, addressing corrosion in wind turbine structures relies on a time-based schedule, involving periodic manual inspections usually conducted annually, significantly inflating overall operations and maintenance (O&M) costs. Given the harsh and corrosive environmental conditions offshore wind turbines (OWTs) endure, corrosion remains a leading cause of structural failures in offshore installations.

Types of Corrosion:

1. Galvanic corrosion
2. Atmospheric corrosion
3. Pitting corrosion
4. Crevice corrosion
5. Stray-Current induced corrosion
6. Corrosion Fatigue
7. Hydrogen induced cracking

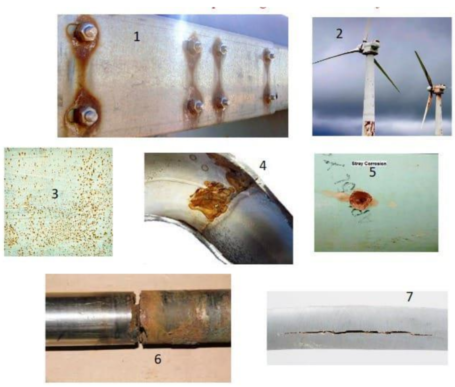

Figure 9. Types of corrosion in marine envoirment

Corrosion of offshore structures is influenced by distinct exposure zones. These zones include the permanently submerged area, which typically employs cathodic protection and coatings. The tidal zone, experiencing wetting and drying cycles due to tidal changes, requires protective coatings due to degradation from chemical exposure, wave abrasion, and microbial activity. Above that, the splash zone endures direct water splashes, leading to increased corrosion as water evaporates and leaves behind salts, often necessitating multi-layer coating systems like those containing glass flake polymers.

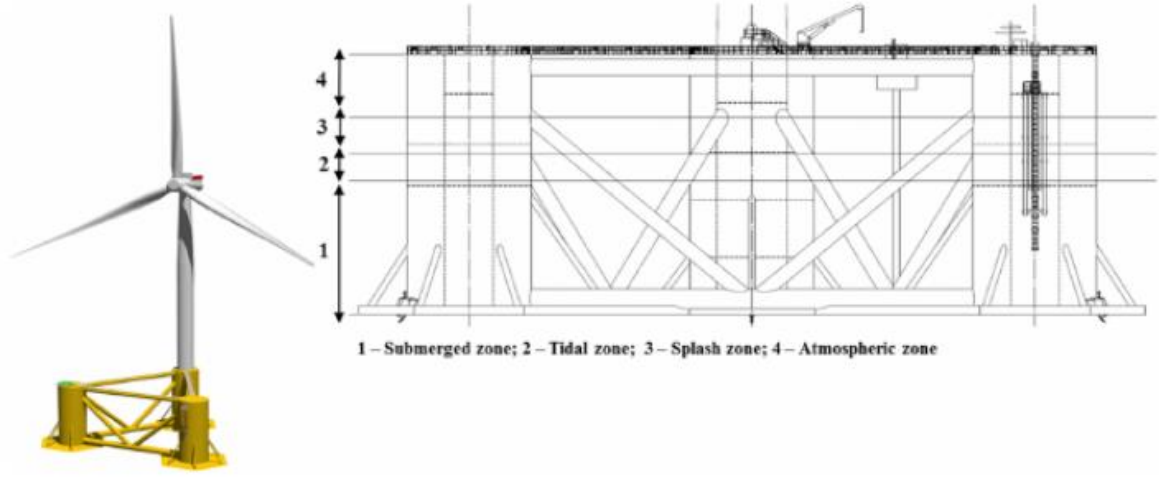

Figure 10. "The Offshore WindFloat platform's structural makeup and regions that are vulnerable to corrosion. PPI, Principle Power Inc. (Emeryville, CA, USA), is given credit.

Monopile foundation structures face both external and internal corrosion concerns. External corrosion, akin to issues in other offshore industries, is addressed following industry guidelines inspired by the oil and gas sector. Cathodic protection (CP) using galvanic anodes is a well-established technique, with DNV-RP-B4011 offering comprehensive guidance on CP design, anode production, and installation. Conversely, internal corrosion protection for monopile wind turbine foundations is not covered by existing industry standards, leaving this aspect to individual owners or designers. In past projects, internal corrosion protection relied on corrosion allowance achieved through increased material thickness, assuming airtight conditions within the monopile structure and low, consistent corrosion rates due to the depletion of dissolved oxygen in seawater.

The calculation of the corrosion allowance (CA) can be determined based on the provided corrosion rates outlined in DNV-RP-0416 (DNV, 2021b, Section 7). The equation describing this process is as follows:

$$CA = V_{corr}(T_D - T_C) \qquad (14)$$

where V_{corr} is the maximum expected corrosion rate, T_C is the expected useful design lifetime of the coating and T_D is the design lifetime of the structure.

14.1.2.4 Wave loading on the wind turbine tower

In the realm of floating offshore wind turbine design, the roles of wind engineers and ocean engineers are distinctly separated. Ocean engineers focus on floater responses independently of the wind turbine superstructure, while wind engineers concentrate on wind loads impacting the turbine. Collaboratively, they work to calculate wave-induced loads by incorporating floater motion.

For catenary systems, both sway and rocking motions significantly affect tower loading, necessitating consideration of their combined impact. Finite Element Method (FEM) simulations indicate that the maximum sway and rocking responses do not necessarily align, yet a discernible correlation exists between them. This correlation draws reference from seismic load specifications in AIJ (Architectural Institute of Japan) standards.

14.1.2.4.1 Equivalent Wave Force of floating wind turbine

Given that the ocean engineer can provide data on the tower base response in actual projects, including displacemen $[x_1]$, velocity $[v_1]$ and acceleration $[a_1]$at the tower base are given. In this research, the tower base response can be derived through simulation, and modal analysis allows for the computation of the equivalent wave force.

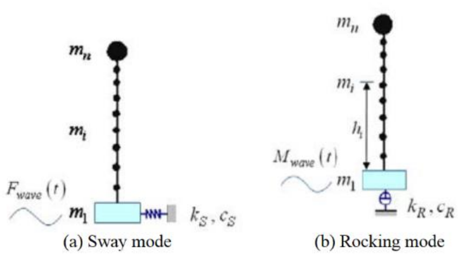

Figure 11. Sway and Rocking mode of turbine tower

Sway motion, also known as surge motion, can be modeled using a lateral spring, while rocking motion, or pitch motion, can be represented with a rotational spring. The influence of floater motion is taken into account by applying a wave force to the floater.

The equivalent wave moment in rocking direction can be calculated by locking the sway mode and using the modal analysis as well:

$$M_{wave(t)} = \frac{\theta_1^R(t)}{\Sigma_{j1}^{n}\left[H_j^R(\omega)\right]\varphi_{1j}^{R2}} \qquad (15)$$

$\theta_1^R(t)$ is te angular displacement at the base of the tower, $\left[H_j^R(\omega)\right]$ is the frequency response function, and $\varphi_{kj}^R(k = 1, \dots \dots, n)$ is the mode shape normalized for the j-th rocking mode.

14.1.2.4.2 Prediction of vave induced load

In cases involving irregular waves, the tower loading exhibits a random behavior. Consequently, the consideration of both standard deviation and peak factor becomes crucial, with their product utilized to determine the maximum load using the equivalent static method. Notably, it has been observed that as the wave period lengthens, the two peaks diminish due to the increased frequency difference from the wave, resulting in a weaker external exciting effect. This diminishing non-Gaussianity with longer wave periods explains the significant skewness (3α) observed in the tower base shear force for tension leg systems, as illustrated in Figure 12, within the 10s-15s period range, but its negligible presence after 16s. The estimation of this skewness is derived from simulations of tension leg floating wind turbine systems. Therefore, for tension leg systems, tower loading is considered a non-Gaussian process, in line with Kareem's model (1998).

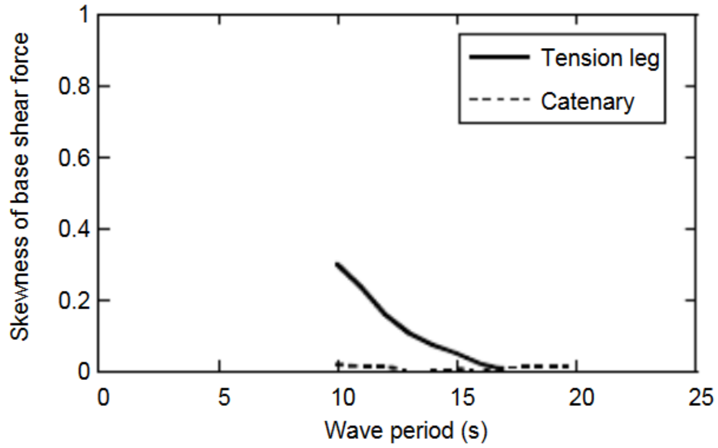

Figure 12. Comparison of the skewness of the tower base shear force produced by a catenary system and a tension leg system

14.1.2.5 Power curve adjustments of OWTs for temperature and altitude

The wind power curve, depicting the relationship between wind speed and wind turbine output, stands as a pivotal characterization parameter for wind turbines. This curve serves multifaceted purposes, enabling the quantification and scrutiny of wind turbine design performance, database monitoring, operational mode control, and product manufacturing oversight. Its utility extends to tasks like rotor size selection for evaluating wind energy potential at potential wind sites and appraising the control mechanisms for operational conditions. In the context of wind farm modeling strategies, primary objectives include optimizing wind power generation and minimizing dynamic loads.

When utilizing established models like the standard atmospheric profile, the annual average air density of a site is regarded as a function of height. This approach is employed to derive mean pressure and temperature values at the given altitude, subsequently determining the consistent air density for that particular site. In cases where wind turbines operate at high altitudes with air densities below the standard sea-level value, it might necessitate a comprehensive blade redesign to accommodate these conditions.

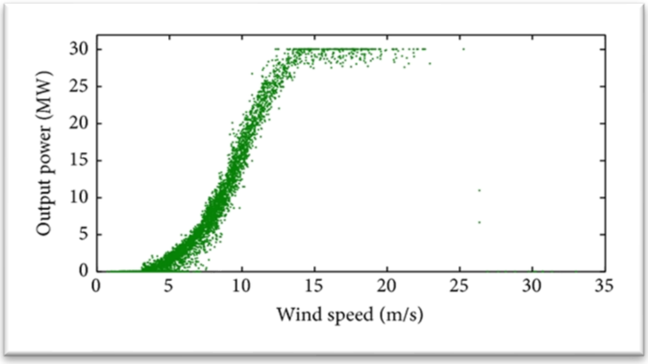

Figure 13. Power curve using actual data for a group of wind turbines at a wind farm (NREL)

The air density in offshore environments is influenced by factors such as pressure, temperature, and humidity, which in turn impact the power output. Site-specific curves have been developed by taking into account the variation in air density to address this effect.The stochastic characteristics inherent in wind power generation can also be represented through the construction of curves, leveraging real-world data derived from power output and wind speed observations in wind farm operations. This methodology does require a substantial amount of historical data but yields precise models suitable for analysis and forecasting.

The impact of moisture on wind energy remains limited at lower altitudes, as evidenced by the minimum altitude employed in the Nassiriyah power plant. However, it becomes more pronounced at significantly higher elevations. In cases of elevated temperatures, the adjustment of the thickness for stickiness is mandated by the IEC standard, as indicated:

$$\rho h = \left(\frac{P}{R_d T}\right)\left(1 - \frac{0.378^{*} e_a}{P}\right) \quad (16)$$

Where,

R_d is the dry gas constant, and e_a is s the current water vapor pressure is equivalent to :

$$e_a = RH \times e_s \quad (17)$$

The power due to wind turbine was calculated

$$P_{wind} = \frac{C_p \rho_h A u^3}{2} \quad (18)$$

P_{wind} is wind turbine power, C_p: pover coefficient A: the rotor area of the wind turbine, u: wind speed. We can apply the ideal gas law and engage in stoichiometric calculations to determine the gas density. This equation demonstrates the temperature-dependent relationship of gas density. The number of moles is denoted as m/M, with m representing the current mass and M signifying the molecular mass of the gas, while density is represented as m/V. It is feasible to derive this equation by examining two distinct environmental scenarios and ensuring the energy produced aligns with it.

$$\omega s_{ref} = \omega s_{real} \times \sqrt[3]{\frac{P_{real} \times T_{ref}}{P_{ref} \times T_{real}}} \qquad (19)$$

The reference values (ωs_{ref},$T_{ref}$and P_{ref}) are the parameters that characterize the operational conditions of the equipment, which are specified by the manufacturer. The SCADA system relies on fixed power curves for predefined or reference conditions during operation.

14.1.2.6 Vehicle-mounted wind turbine

The Vehicle Mounted Wind Turbine (VMWT) is a system that mounts a horizontal axis wind turbine on vehicles to generate electricity. This paper outlines the design and implementation of VMWT for vehicle-based electricity generation, featuring smart attributes such as a high RPM turbine, convenient weight, practical shape, and portability. The design process for VMWT requires careful consideration, as it shares a basic configuration with Horizontal Axis Wind Turbines (HAWT) but has distinct design criteria due to its unique application.

When the vehicle is in motion, the turbine rotates at a significant RPM, generating mechanical torque (mechanical input) that drives a generator to produce electrical output stored in the battery for future use. Additionally, the efficiency of the turbine blades concerning air force and vehicle speed is considered.

$$V_1' = V_1 \frac{\sqrt{m_1^2 + m_2^2 + 2m_1 m_2 + cos\alpha}}{m_1 + m_2} \qquad (20)$$

Where V_1' is the speed after collision for first object, V_1 is speed before collision for first object , m_1 is the mass for first object, m_2 is mass for second object, θ is the angle of deflection.

Incorporating wind turbines into vehicles offers numerous benefits in terms of sustainable energy generation. These turbines can be applied across various domains, including maritime applications at sea, installation on ships, land-based integration in automobiles and trains, as well as aerial use in airplanes.

14.1.3 Types of Wind Turbines for Marine Applications

Typically, fixed foundation offshore wind turbines are deemed technically feasible in regions where water depth does not exceed 50 meters (160 ft) and where average wind speeds are above 7 meters per second (23 ft/s). Contrary to the traditional marine industry interpretation of "offshore," offshore wind power encompasses locations both near the shore, including lakes, fjords, and sheltered coastal zones, as well as deeper waters. While most offshore wind farms employ fixed-foundation wind turbines in relatively shallow waters, the utilization of floating wind turbines in deeper waters is still in its initial phases of development and deployment.

14.1.3.1 Bottom-Fixed foundation

Fixed wind turbine supports of many forms are available for turbine installation, depending on the level of the water and ground constraints.Gravitational foundations are used in shallow depths (0-30m) and consist of large slabs of steel or concrete bases that are set on the floor. Pulling scoop piles, which are likewise made of steel or concrete, are installed without the use of mechanical power by using the fluid pressure disparity formed between the bucket's interior and the surrounding water. Monopile bases, which are utilized in low-lying waters (0-30 m), are made out of a caused pile inbuilt in the seafloor and are frequently preferred for their cost-effectiveness, making them the most generally employed support form.

Tripod fixed bottom supports are used in medium altitudes (67-262ft) and consist of three legs connected to a central shaft that supports the turbine foot. Each leg is anchored with a pile driven into the seabed, providing a wide base that allows for shallower pile the installation in the ground than monopile underpinnings.

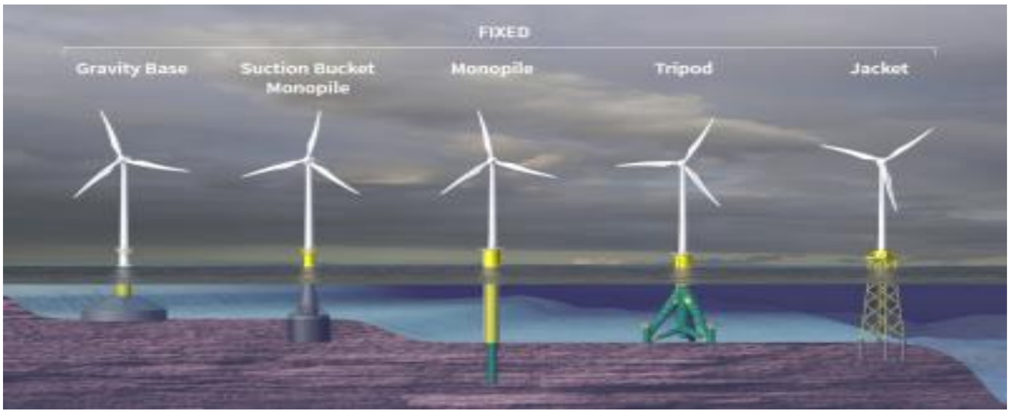

Figure 14.Types of Fixed Offshore Wind

14.1.3.2 Floating

Floating wind turbines (FWTs) can be categorized as stabilized by ballast, buoyancy, or mooring systems during their operational phase. In practice, many FWTs utilize a combination of these stabilization methods. The figure illustrates the relative positions of various commercial FWT concepts within the restoring mechanism triangle. It's worth noting that certain floating foundations, such as spar and tension leg platform (TLP), exhibit distinct restoring characteristics during transportation and installation compared to their operational phase. Additionally, there are significant variations among FWT designs, often requiring customized installation approaches for each specific concept.

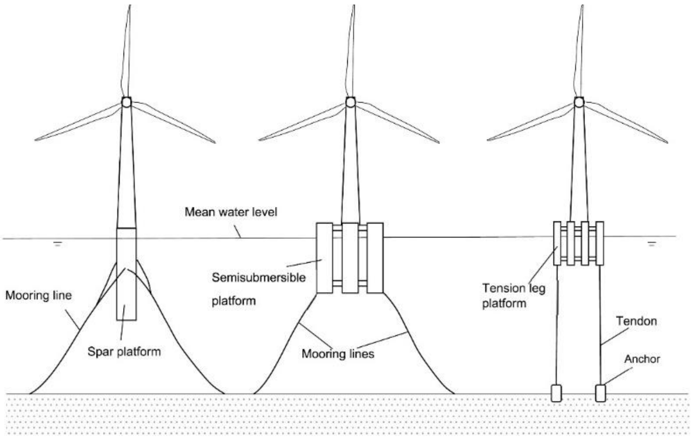

Figure 15. Structural layouts of floating wind turbines, including tension leg platform configurations, semisubmersible platforms, and spar platforms.

Every platform is tasked with the responsibility of bearing the weight of the wind turbine and maintaining stability during its operation. This is achieved, in part, through the use of hollow platforms, typically constructed from substantial steel or concrete structures, which offer buoyancy to uphold the turbine. Floating platforms have the capability to support wind turbines with the capacity to generate 10 megawatts or even more – a scale comparable to conventional offshore wind turbines and multiple times larger than the output of a standard onshore wind turbine commonly found in open fields.

14.1.3.3 Hybrid Offshore Wind Turbine

Emerging technologies propose an innovative hybrid strategy that unites wind and wave energy to optimize their collaboration, thereby decreasing common expenses such as mooring and electrical connections.

These hybrid systems harness both wind and wave energy within the same marine environment, presenting a promising renewable energy solution for the future. The viability assessment of the hybrid concept is conducted through the utilization of the aero-servo-hydro-elastic simulation tool FAST. This investigation delves into the interactions between the integrated system components to assess the impact of the Wave Energy Converters (WECs) on the Semi-Submersible Tension Leg Platform (STLP) platform across different operational scenarios of the wind turbine, including both regular and irregular wave conditions.

The key characteristics of the hybrid wind turbine with a floating platform are outlined as follows:

These WECs generate electrical power by revolving the arms around hinges positioned around the central cylinder. Each arm of the WEC is affixed to a hydraulic power take-off (PTO) system, which converts the mechanical rotational energy of the arms into hydraulic and electrical energy.

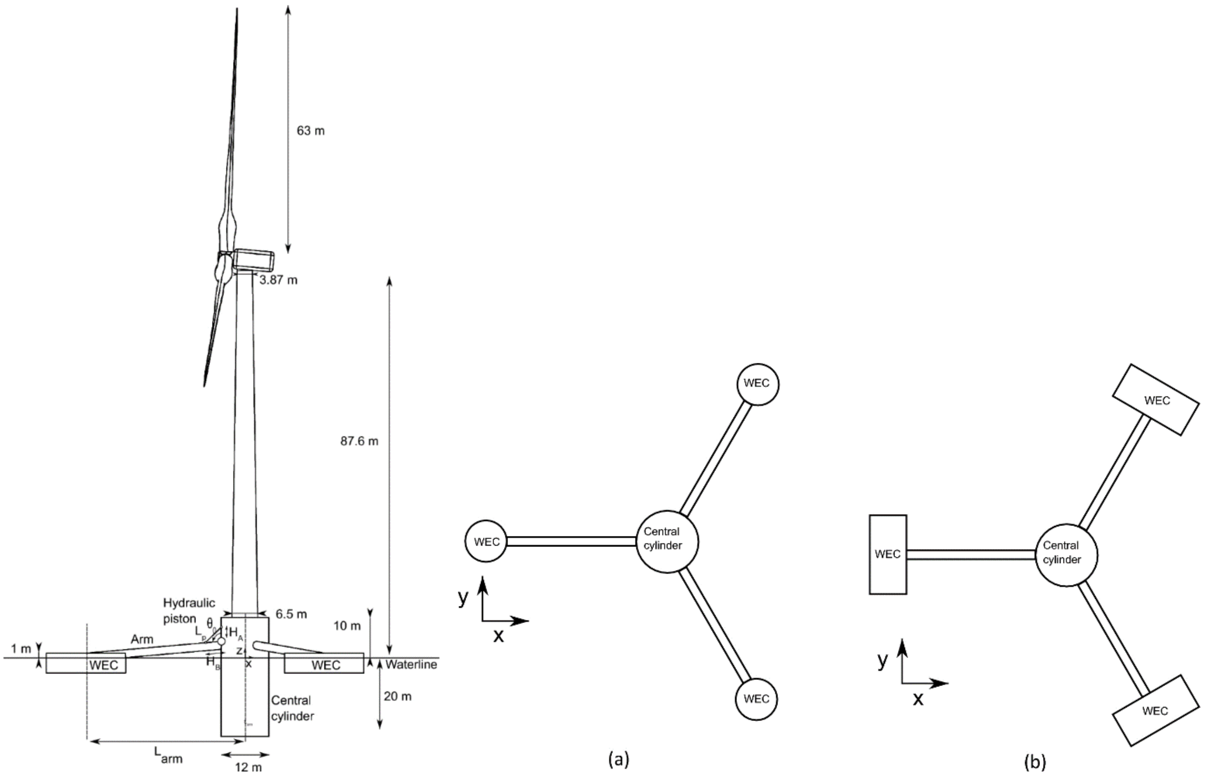

Figure.16 Layout of the WECs for the cylindrical and spherical shape (a) and the semi-cylindrical shape (b). Wave and wind directions are shown by the x-axis

A project that integrates wind and wave energy extraction offers various advantages, including a more dependable power output, as illustrated by the layout of the WECs for the cylindrical and spherical shapes. Wave energy can serve to mitigate the motion of offshore wind turbine platforms through both active and passive means. Wave energy converters (WECs) function by absorbing energy from ocean waves, consequently reducing the wave field and creating a shadow effect that naturally dampens platform motion induced by waves. Additionally, WECs can be actively controlled to actively mitigate the motion of offshore wind platforms, reducing the risk of system fatigue and optimizing wind turbine performance by minimizing hub motion. While the active suppression of offshore platforms with WECs is still in the early stages of research, numerical and test tank results show promise for its effectiveness.

In summary, the integration of wave energy into hybrid wind-wave systems shows great potential in shaping the future of offshore wind energy. The key benefit of combining wave energy with floating offshore wind is the mitigation of platform motion and the ability to meet local power needs. Wave energy converters (WECs) offer effective platform motion suppression through passive and active control techniques. While research and development in the field of hybrid wind-wave systems are relatively recent, promising examples like the W2Power and Poseidon case studies have advanced to ocean demonstration stages.

14.1.4 Future Trends and Innovations

The offshore wind energy sector is currently experiencing significant transformation, marked by pioneering advancements and upcoming developments that are set to revolutionize the field. With the growing worldwide need for clean energy solutions, offshore wind turbines are positioned to have a more substantial impact in achieving sustainability objectives. This document provides insight into the most encouraging innovations and emerging patterns that will shape the future of offshore wind turbine technology.

14.1.4.1 WindFloat Atlantic

The offshore wind energy sector is currently in a state of rapid transformation, characterized by groundbreaking innovations and forthcoming trends that have the potential to reshape the entire industry. As the global demand for clean energy continues to rise, offshore wind turbines are positioned to play an increasingly vital role in achieving sustainability objectives. This document offers a glimpse into the most promising innovations and emerging trends that are driving the future of offshore wind turbine technology. Following several years of dedicated work, the project achieved full operational status in July 2020. By the end of 2022, WindFloat Atlantic had accumulated a total cumulative production of 180 GWh, meeting its planned targets.

The offshore wind power plant comprises three wind turbines, supported by three semi-submersible floating structures using the "WindFloat" technology developed by Principle Power. The specifications of the wind turbine towers are as follows:

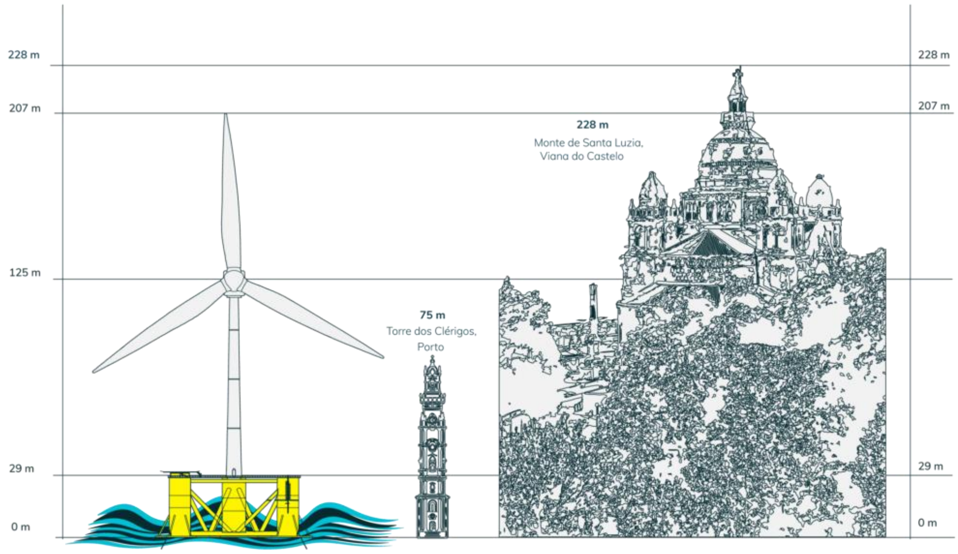

Figure 17. One of the huge turbine in Porto

The triangular floating platform is designed to be semi-submersible and firmly anchored to the seabed. It comprises three vertical columns that are interconnected and mutually supportive, with one of these columns being affixed to the wind turbine tower's base. The lateral separation between the columns, measured from their centers, spans approximately 50 meters. To enhance its stability, the platform utilizes a system of chambers filled with water located at the base of the three columns. This is complemented by a static and dynamic ballast system that actively adjusts the water distribution between the columns to counteract the wind thrust exerted on the wind turbine.

14.1.4.2 The Redwood Coast Offshore Wind Project

RCEA and a group of developers have come up with the first commercial-scale task, called the Redwood Coast Offshore Wind Field.

A Demand for Specifications was launched by RCEA in 2018 to find potential development collaborators. The Board of Directors of RCEA then decided to work with a group of businesses to pursue the growth of local wind power from the ocean. In anticipation of acquiring an agreement for lease, the project business is diligently collaborating with local stakeholders to develop a project plan that minimizes environmental consequences and optimizes benefits to the neighborhood. The effort will be the result of substantial grassroots participation and engagement and is projected to take a long time to plan and execute.

Redwood Coast Offshore Wind Project

- 100-150 MW
- 25 miles or so west of Eureka
- Seafloor depth ranges from 2,000 to 3,600 feet.

There are four sections to explain the project's guiding concepts.

Project Guidelines

- Offer electric ratepayers green energy at fair prices.
- Prioritize stakeholder participation and acceptability; find and handle local concerns.
- Reduce the negative effects of development on the environment.
- To make Humboldt Bay an industrial powerhouse, spend as much as possible in the regional infrastructure.

While waiting for the Bureau of Ocean Energy Management to decide on the final lease units during the 2022 lease auction procedure, the choice of the project location was affected by a number of crucial variables, especially its accessibility of roughly 205 square miles of territory. To guarantee limited interruption, current commercial fishing and shipping activities in the area were also taken into account. Furthermore, wind resource converts have been reviewed so as to determine optimal conditions for the wind for the generation of energy, and wildlife and environment inspections were carried out to mitigate environmental impact while addressing technical constraints to minimize grid interconnection distances for greater reliability and delivery of energy.

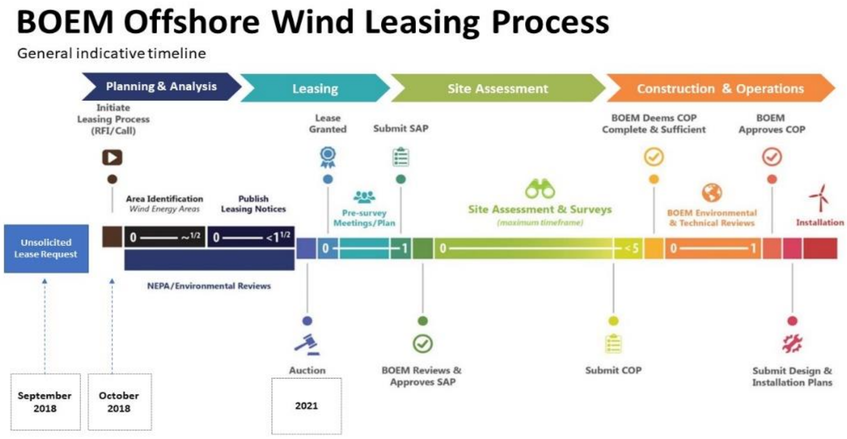

Figure 18. BOEM Offshore Wind Leasing Process

14.1.4.3 Batwind project

The 1.3MWh Batwind battery, jointly owned by Masdar and Equinor, plays a crucial role as an energy storage solution for the world's inaugural commercial floating wind farm, the 30MW Hywind Scotland. Launched on June 27, 2018, Batwind employs advanced data-analysis algorithms to efficiently oversee the storage and discharge of electricity, thereby optimizing its economic value. These algorithms rely on diverse data sources, encompassing weather predictions, market pricing, maintenance schedules, consumption patterns, and grid services, to ensure that the battery's intelligent energy system maximizes its usefulness and revenue generation. Situated at an onshore substation in Peterhead, Scotland, Batwind captures the electricity generated by the Hywind floating offshore wind farm.

Figure 19. High capacity batteries

A significant benefit of integrating these batteries into this project is the necessity for electricity grids to operate in real-time and constantly balance supply and demand for seamless functionality. Consequently, managing the fluctuations in energy supply from solar and wind sources can be a considerable challenge. Storage solutions effectively tackle this challenge by enabling operators to access electricity from solar and wind sources as needed, ensuring a stable and reliable energy supply.

14.1.4.4 Icebreaker Wind

Icebreaker Wind represents a distinctive wind energy initiative, marking the inaugural offshore wind facility in the Great Lakes, the foremost freshwater wind farm in North America, and just the second offshore wind project in the entire United States. In essence, it provides Ohio with the chance to assume a prominent role in the burgeoning offshore wind sector on a national scale.

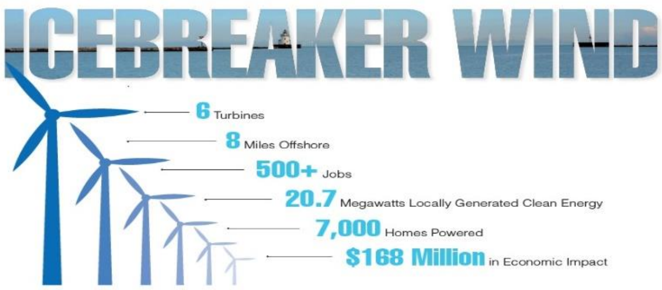

Figure 20. Energy project of Icebreaker Wind

On August 10, 2022, the Ohio Supreme Court, in a 6-1 ruling, upheld the state permit granted to Icebreaker Wind, clearing the way for the project to proceed. This legal challenge, initiated by two Bratenahl residents, represented the final legal obstacle to the development of North America's inaugural freshwater offshore wind turbine installation. Throughout the process, Green Energy Ohio (GEO) provided unwavering support to Icebreaker Wind.

On May 21, 2022, the Ohio Power Siting Board, with unanimous consent, eliminated the nighttime "feathering" requirement from their order regarding Icebreaker Windpower. GEO had criticized the initial decision, considering it a hindrance to the project's financial viability. The amendment proposed by Director

Mary Mertz of the Department of Natural Resources paves the way for Icebreaker to advance toward final approval.

The deployment of wind turbines in maritime settings is experiencing continuous growth in today's world. This expansion encompasses various strategies and challenges while also drawing on prior initiatives to improve techniques and power generation. There are several notable ongoing and advanced projects, focused on future applications and data acquisition, contributing to this evolution.

14.1.5 Advantages and Disadvantages of OWTs

These turbines are designed to harness the power of wind and transform it into electrical energy. According to the American Geosciences Institute, wind speeds over the ocean are generally higher compared to those on land, and even slight increases in wind velocity can lead to substantial increases in electricity production. The elevated offshore wind speeds offer a significantly greater capacity for energy generation. Moreover, offshore wind speeds tend to be more consistent than those experienced on land, ensuring a reliable and stable energy source.

14.1.5.1 Advantages of OWTs

Offshore wind farms are located far from shore within the lakes and ocean. Though they are less frequently built, they have their set of pros and cons.

14.1.5.1.1 Generates More Energy

On average, offshore wind farms have the capacity to generate over 1 MW of power, surpassing the potential of onshore wind farms. Unlike onshore wind turbines, which are constrained by height limitations, offshore turbines can be built to larger specifications. With their substantially larger turbine blades, they can produce greater amounts of energy. Additionally, the consistently higher wind speeds at sea, as compared to land, enable offshore wind farms to generate more substantial power outputs.

14.1.5.1.2 More wind consistency

Offshore wind speeds exhibit less variability, and wind direction changes are less frequent, resulting in greater consistency and reliability in power generation from offshore turbines.

14.1.5.1.3 Less Intrusive

Situated in sea or lake regions, offshore wind farms are less obtrusive compared to their onshore counterparts. They do not encroach upon private land used for farming or grazing and do not disrupt neighboring countries, buildings, or obstruct their surroundings. Moreover, offshore wind farms occupy larger areas per square mile, resulting in a reduced physical footprint and environmental impact.

14.1.5.1.4 Bigger turbines

Offshore turbines can achieve greater heights than their onshore counterparts, as they are less accessible to the general public. This extended height allows them to capture more wind energy and generate increased electricity output.

14.1.5.2 Disadvantages of OWTs

Despite their numerous advantages, offshore wind farms do have some significant drawbacks. One of the most commonly cited concerns is the impact on the aesthetic beauty of the surrounding areas, with people expressing concerns about the visual disruption they cause to the natural landscape.

14.1.5.2.1 Less Local Involvement

Now, turning to the list of pros and cons of offshore wind farms, let's start with the cons. Unlike onshore wind farms that are often owned by local businesses, offshore wind farms typically require substantial investments, making it challenging for local enterprises and organizations to participate. These projects are typically owned by large corporations, and while they do create job opportunities, they may not always directly benefit specific local communities. Consequently, offshore wind farms may not provide the same level of economic opportunities as their onshore counterparts.

14.1.5.2.2 Maintenance & repairs

During periods of extreme sea waves, tides, or strong winds, offshore wind farms are more susceptible to turbine damage, necessitating increased maintenance compared to their onshore counterparts.

14.1.5.2.3 Noise & visibility

The sounds emitted by underwater turbines can have adverse effects on marine fauna and other underwater life. Additionally, it's important to note that not all offshore wind farms are situated out of sight from the public. Some are constructed within 26 miles of the coastline, which can still be visually disruptive for local residents.

14.1.5.2.4 Less local jobs

The capacity for offshore wind farms to contribute to local economies is constrained in comparison to onshore wind farms. This limitation arises because manufacturers' offices are typically situated inland, often at a significant distance from the offshore sites, resulting in a lack of job opportunities and other economic developments within the nearby communities.

Considering both the advantages and disadvantages of offshore wind farms, I hold the view that, at its current state, this technology may not be suitable for large-scale implementation. However, as technology advances and materials become more cost-effective, the potential for deploying offshore wind farms on a massive scale may improve.

Overall, I strongly believe that green energy plays a crucial role in combating climate change. Nevertheless, the average consumer often prioritizes one key factor: cost. Until wind energy becomes more cost-competitive and reliable compared to other energy sources, it will face significant challenges in surpassing fossil fuel production.

Conclusion

This article is written to explain the field of application ,properties,effect of parameters on the power of wind turbines in the offshore environment. The first part of the discussion is about a number of parameters that affect the power of the wind turbine in the offshore environment. In the first part, the parameters that can increase the efficiency of the turbine are highlighted in detail, which include: wind speed and length of wind season, diameter of the rotating blades, the efficiency of wind turbine components, pitch control, arrangement of the turbines in the farm. The other part is devoted to the factors that can reduce the power of the turbine, which include: aerodynamic drag, blade friction, and air density. Here we could touch on more parameters that can both increase and decrease the efficiency of the turbine, but the author tried to touch on the main factors here. In another part of the article, it was mentioned about the corrosion of the turbine.

Various types of corrosion are shown here, as well as the ways in which it can be prevented in its offshore environment. As we know, because there are waves in the marine environment, it is important to emphasize here the effect of the wave on the turbine. For this reason, wave loading on the wind turbine tower is mentioned in another section. Temperature and pressure are one of the main parameters affecting air density. As mentioned in the research, the efficiency of the turbine can increase or decrease depending on the density of the flowing air. Considering these two effects, they were added to the other part of the study. The application of wind turbines in the means of transportation in cities, as well as in airplanes, has made it possible for us to apply these turbines in a more advanced form to ships. In this case, mainly because the wind's durability plays a role, how to change it in form is explained in the vehicle-mounted wind turbine section. As we know, the types of wind turbines in the offshore market, the different classes of these types and the classification according to which factor must be mentioned in the research, so the information about this is included in the paragraph.

Since the development of turbines in the marine industry is a somewhat slow process, the record of innovative ideas applied to wind turbines will provide readers with other innovative ideas. In the investigation, it is possible to see the record of the projects implemented in the recent past and the development continues. In conclusion, we discuss the pros and cons of these turbines, which are best suited for offshore settings. Presenting both the advantages and disadvantages to readers helps them evaluate real-life projects based on their own principles, highlighting potential challenges.

When the author conducted this research, he came to the conclusion of the lack of application of wind turbines on ships. Based on the results of the investigation, it can be said that we can fill this gap by applying VAWTs to ships. Considering the constant wind in a dynamic environment, the principle of carrying out long-term trips with a ship means that we need a large amount of electrical energy. Here we can use the energy we get with the wind turbine to supply the ship's electricity. In general, the energy received by the ships from the generator and the energy received from the wind turbine can be used in a hybrid form, and we can gradually reduce energy consumption and CO_2 emissions.