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Renewable Energy: Wind Turbine Applications in Vibration and Wave Harvesting

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Abstract--- Wind turbines are famous devices used for generating electricity from wind energy but they can now be in various applications wherein they are used for harvesting energy from vibrations and wave motions of the sea. This article analyses the applicability of wind turbine technologies for harvesting energy from vibration and wave of the environment thus adding a new face to the renewable energy resource. Combining vibration and wave methods of energy generation with the conventional wind turbines make it possible to capture energy in a more diverse and productive way, especially where there is both winds and great waves, as is in the coastal and offshore regions. The article brings out details relating to these systems, pertaining to piezoelectric and electromagnetic processes of converting mechanical energy into electrical power. It also considers the prospects of electromechanical hybrid systems of wind, wave, and vibration energy conversion to produce maximum power and ensure high efficiency. Some of the problems like integration of the system, optimization of its efficiency, and ways in which these elements are affected by external environment are considered. Examples of the scientific and experimental and operating projects in one or more areas of this technology remarks on possible advantage and real world use of this technology. Hence, exploring the versatility of wind turbine applications as a means of producing electricity through vibration and wave energy can be considered as an innovative breakthrough to the future of renewable energy systems.

Keywords--- Electromagnetic Harvesting, Energy Harvesting, Hybrid Systems, Piezoelectric Methods, Renewable Energy, Wave Energy.

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I. Introduction

With countries across the globe facing climate change/environment issues and the need to tap into clean, renewable sources of energy, Wind turbines as a form of renewable energy continues to rise on the map as the important source of power as civilization adjusts to the changes in climate. It is these colossal structures that help in producing clean electricity through wind without polluting the environment and thus providing a noble fight against global warming (Ahmed et al., 2017). Wind energy has been on the rise for the last few years, wind mills are getting more efficient, cheaper and effective in converting kinetic energy into electric power shown in Figure 1.

Wind turbines are no longer restricted to the conventional application of power generation but has diversification into the realms of vibration and waves, and more. This paper focuses on the flow phenomena on wind turbines, the associated vibrations and the techniques to harness power from these vibrations. It also includes an analysis of features of the ocean waves and the power systems employed in the conversion of the energy of waves. Besides, it also explores the possibility of combined wind-wave energy systems and also analysing the environmentally friendly renewable energies (Jahangiri & Sun, 2019).

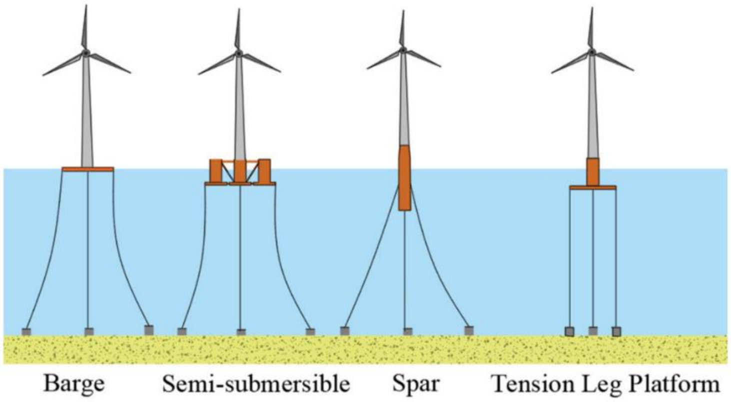

Figure 1: Conventional Application of Power Generation

II. Wind Turbine Aerodynamics

It is thus important to understand how wind turbines are designed and what role the aerodynamics of the turbine has towards its performance and energy output. The study of the various forces likely to affect the turbine blades and how various wind conditions impact on the wind energy collection is crucial (Rostami & Armandei, 2017).

2.1. Blade Design Principles

Bigger blades for windmill has been designed and constructed to generate as much power as possible while it's being constructed at an affordable price as possible. The turbine design that is considered to be more efficient now could not be like this several years down the line. Today's wind turbine blades are smaller, less noisy, and are designed in such a way as to produce more power from less wind.

The fact that an turbine blade is curved in nature is as basic as it gets. It gives a pressure difference on the face of the blade and on the back of the blade leading to generation of lift. The side with the most curve has low air pressure while on the other side of the blade-shaped aerofoil high pressure is exerted by the air. This leads to generation of a lift force acting perpendicular to the direction of the flow over the blade.

Further, blade design aims at having the required lift and thrust to slow the amount of air to enhance the efficiency of the blades. The TSR represents the ratio between the rotor tip speed and the in Wesent speed of the wind; it is affected by the blade shape profile, number of blades and general design of the turbine.

New blade design has also seen the inclusion of slightly curved blade which can harness by 5 to 10 percent more wind energy with efficiency at lower wind speed (Elias & Beer, 2024). It has been acknowledged that computational fluid dynamics (CFD) can be a useful means in the assessment and enhancement of blade designs shown in Figure 2.

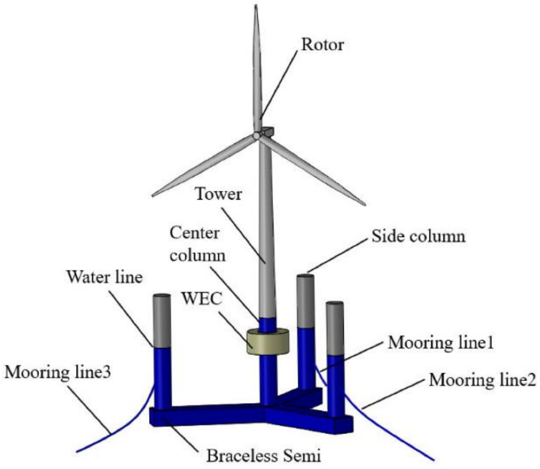

Figure 2: Enhancement of Blade Designs

2.2. Lift and Drag Forces

Wind turbine blades are subject to four primary forces: drag, lift centrifugal and gravitational force. These forces are important to comprehend in an effort to develop better and long lasting wind turbines.

This is forces or pull exerted by the wind or air molecules on the face of the blade that it is pointing to. A substantial part of the drag force operates along the primary axis of the rotor shaft. The amount of drag depends with the speed of the wind as well as the size and shape of the blade being used. It can be appreciated from the figure that drag forces produce a cantilever beam effect causing maximum stress at the blade hub joint.

Lift forces on the other hand are developed as a result of pressure differences from the front and rear area of the blade in flight. A substantial portion of the lift force likewise operates in a constantly varying tangential direction relative to the rotor's rotation. The amount of lift that is generated also depends with the velocity of wind, size and the shape of blades. This is because as the load in the generators rise the amount of lift that may have to be supplied must also rise but within the available wind conditions.

More importantly, the drag and the lift forces are orthogonal to each other. These forces have cantilever beam action on the blade in which highest stress is experienced at blade joint with the hub.

Here the forces act in radial direction and the stress is tension type and it is acting from root to the tip of the blade. These forces depend on the size and shape of the blade, density of the blade and the angular velocity of the rotor.

Gravity forces are always acting towards the earth's center of gravity and their impact on the blade is varies as the rotor spins. According to the analysis, maximum tensile or compressive stress would be in the radial direction when the blade is in the vertical position and maximum bending stress will take place at the horizontal position of blade.

2.3. Wind Shear and Turbulence Effects

It has been established that wind shear as well as turbulence effects worst the wind turbine reliability and lifespan. Wind shear- change of wind speed or wind direction with altitude or height and turbulence on the other hand refers to rapid variation of wind speed and direction.

The wind power generation is a direct function of wind speed although it is restricted by factors including static stability, shear, and turbulence. These influence power production by changing the inflow speed and direction profile or wake effects of other up turbine.

Wind shear when defined can be in terms of the speed shear which is the change of the horizontal wind speed with height and the directional shear which is the change in wind direction with height. The two forms of shear interlink with the amount of power that can be realized in the air stream passing across the turbine and the efficiency of its ability to harness energy from the wind stream (Zheng et al., 2023).

Research has revealed that the parameters of speed shear exponent varies between 0 and 0. A smaller value of 33 des increases available power over the rotor swept area, whereas a larger value of LES provides more energy flux than the uniform flow at the hub height. Further, the direction of the wind changes with height, and the wind speed at a height record by a wind turbine differs from that at ground level, and thus, the relative velocity of the air with the blades or the effective angle of attack of the blades is not optimal because the pitch angles of the blade cannot be optimal for all winds speeds as the wind speed changes (Kong et al., 2019).

Another significant factor is the turbulence intensity that has an influence on the dynamic loads of wind turbines. High turbulence also means applied cyclic flex and axial loadings which means that the components of the turbines would require to be replaced after some time.

These flow phenomena are intricate and require detailed comprehension for reliable simulation of wind turbine performance, and on this basis, design optimization for longevity of wind energy conversion systems in operation.

III. Mechanical Vibrations in Wind Turbines

Vibration is a critical issue in wind turbines because they are massive machines with numerous complicated components through which mechanical forces might be transmitted and accumulated creating challenges in their design shown in Figure 3. These vibrations result from wind turbulence, wind shear, gravity, tower shadow, and/ or mass and aerodynamic imbalances, and wake effects. These vibrations have to be controlled and understood for effective and efficient day to day running of wind turbines and their designs.

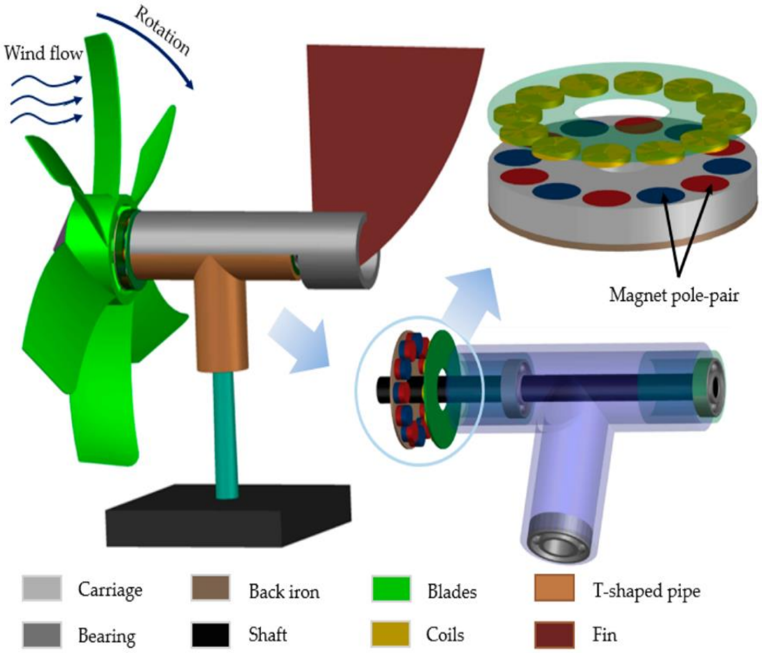

Figure 3: Mechanical Vibrations in Wind Turbines

3.1. Eigenfrequencies and Shapes

Likewise, the natural mode shapes and frequencies of wind turbine components and especially the rotor blades are quite essential in determination of their vibration response. These characteristics depend with aspects like the type of material used, the design on the blade and the overall size of the turbine. Preliminary design includes the estimation of the natural frequencies because they are critical to prevent resonance of the structure which can result in a catastrophic failure.

To analyze the vibration behavior of wind turbine blades, engineers often employ simplified finite element beam models. These models typically use the lowest eigenmodes of the rotor blades to describe their elastic deformation within a multi-body system framework. Generally, the first two bending eigenmodes in both flapwise and edgewise directions, along with two additional torsional eigenmodes, are utilized.

The Timoshenko beam theory is preferred over the Euler-Bernoulli beam model for these analyzes, as it incorporates the effects of transverse shear and rotational inertia on the dynamic response of the beam. This approach provides a more accurate representation of the complex blade geometry and material properties.

3.2. Forced Vibrations in Turbine Components

Wind turbines experience forced vibrations due to various external factors. One significant phenomenon gaining relevance, especially as turbines become larger and more flexible, is vortex-induced vibrations (VIVs) on the blades. These vibrations occur when the turbine is not in operation, such as during maintenance, storm conditions, or erection.

That during these periods the wind can come from different directions as seen in the figure lower right that causes large angles of attack near the chord line that is perpendicular to the blade length. This situation can result into deep stall with a high level of vortex shedding which makes lock-in between structural frequency modes and shedding frequencies more likely.

The complexity in analyzing VIVs is because it is a function of the shedding frequency and phase angle between corresponding loads and motion velocity. This phenomenon cannot be calculated using traditional engineering Models accurately especially because the chord of the blade varies along span length. Consequently, traditional methods such as high-fidelity methods including computational fluid dynamics (CFD) have to be employed for precise analysis.

These are the positions of VIV branches based on blade shape and structural features as well as flow velocity. That is why, though one can change the blade shape and move VIV regions using a tip or flap, which is very difficult within realistic alterations to exclude the risk fully.

3.3. Vibration Damping Techniques

To mitigate the effects of mechanical vibrations, various damping techniques have been developed:

1. **Tuned Mass Damper (TMD):** The advantages of this passive system are that it can achieve up to 55% of reduction in floating offshore wind turbines vibrations.
2. **Tuned Liquid Damper (TLD):** A device that performs energy dissipation through liquid movement on containers; when optimized has the capability of having greater than 70% energy dissipation rates.
3. **Controllable Fluid Damper:** For harmonic loading the degree of vibration damping is enhanced by 25-30% and for random loading 10-15%.
4. **Active Control Systems:** Some of them are individual pitch control and trailing edge flaps. The individual pitch control has proved to achieve fatigue load reductions ranging from 20-40% while the trailing edge flaps have fatigue load reduction rates of up to 90% in experiments.
5. **Compliant Wing Design:** That is, in essence a no-hinge constant-radius structure can distribute movement and power through elastic deformation providing flexibility as well as an external load-bearing resistance.

When employed effectively, these damping techniques can greatly improve the characteristics, durability and efficiency of wind turbines through the mitigation of mechanical vibrations and companion fatigue loads. With the ongoing improvements in the wind turbine technology, the effectiveness of the above mentioned vibration control strategies will become a critical area of future development more specifically geared towards achieving maximum power output with minimum maintenance costs.

IV. Investigation of Vibration Energy from Turbine Use

Conventional wind turbines, intended mainly for utility-scale electricity production, also include possibilities for extracting energy from their inherent oscillations shown in Figure 4. This approach has however attracted a lot of attention in recent years especially in powering wireless sensor networks (WSNs) and internet of things (IoT) devices in remote locations. This way the vibrations created by wind turbines can be actually transformed into electricity using a number of methods, making wind turbines a prospective answer to the problems of localized electricity provision (Zhang et al., 2024).

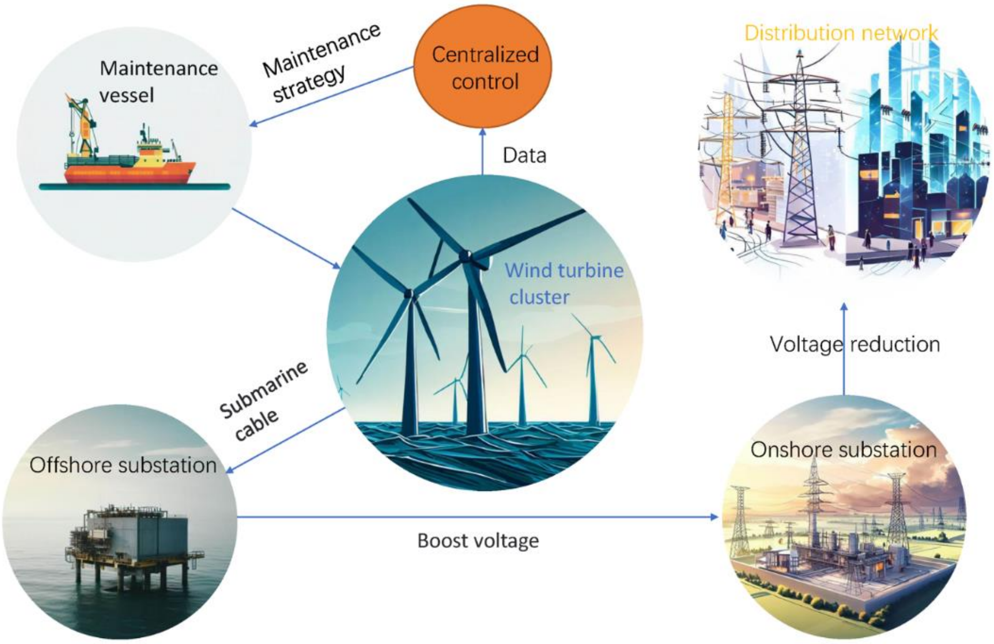

Figure 4: Investigation of Vibration Energy from Turbine Use

4.1. Piezoelectric Energy Harvesting Mechanisms

Piezoelectric energy harvesting has potentials of converting the vibration of wind turbines into electrical energy that can be used. This technique employs the materials that release an electric charge when receives some mechanical pressure. In wind turbine cases, the piezoelectric harvesters are to be affixed on the surface of structures to harvest energy from vibrations of blades, oscillation of the tower, and other dynamic motions.

The piezoelectric wind energy harvesting can be effectively illustrated with an example of the rotational piezoelectric wind energy harvester designed by Yang et al, However, the ball-impact-induced resonance has shown to amplify the mechanical to electrical energy conversion. Another solution explored by Fu and Yeatman, involves magnetically coupled piezoelectric beams and frequency upconverted to develop a broadband low-speed rotational energy harvester which can self adjust and accommodative for a broad range of speed in the air (Ahmadi et al., 2019).

4.2. Electromagnetic Induction Harvesters

Another efficient approach of utilising energy derived from wind turbine vibrations is electromagnetic induction. This approach usually entails the process whereby a magnetic field is made to move either round a coil or in the vicinity of it and this in turn creates an electric current. The Electro Magnetic harvesters are interesting because they have a basic structure, high output power, low maintenance and have not shown any signs of decay in the long run.

Three-dimensional printed air-driven rotational electromagnetic energy harvesters have been designed and validated. These devices contain relatively simple designs, comparatively low costs of construction, and short assembly times for prototypes. In another study, Wu and Lee developed a miniature windmill-structured electromagnetic energy harvester for monitoring forest fire via wireless required analysing different blade types for aerodynamic efficiency.

4.3. Triboelectric Nanogenerators for Wind Energy

Triboelectric nanogenerators or TENGs have been recently introduced as a potentially powerful type of wind energy harvesting. Wind-based TENGs (W-TENGs) offer several advantages, including:

1. Versatility of performing a wide variety of tasks at variable wind speeds.
2. When it is: Capability to harvest omnidirectional wind.
3. Relatively high power density.
4. He simple structures and keener focus on shrinking size and reducing the weight of structures.
5. Installation of these turbines is quite simple hence the costs of operation are relatively low.

W-TENGs could be significantly advantageous in situations where ordinary harvesters cannot be easily utilized such as for harvesting energy from subtle wind gusts, Youths movements and High-speed train and highway wind. They are small in size thus can be deployed in areas with high density as a source of power for small electronic gadgets, monitoring the environment and part of the sensor system.

The architecture of W-TENGs varies depending on their working principle, with most designs based on either contact separation mode or horizontal sliding mode. Recent advancements have demonstrated stable operation for over 1,400,000 cycles, making W-TENGs suitable for applications such as smart farming, wind speed monitoring, and anti-glare panel arrays on highways.

In conclusion, energy harvesting from wind turbine vibrations presents a promising avenue for powering small-scale devices and sensors. By leveraging piezoelectric, electromagnetic, and triboelectric mechanisms, researchers and engineers are developing innovative solutions to capture and utilize this otherwise wasted energy. As these technologies continue to advance, they are expected to play an increasingly important role in powering the growing network of IoT devices and sensors in remote and urban environments alike.

V. Ocean Wave Characteristics

Ocean waves play a crucial role in the marine environment, representing a significant potential for renewable energy shown in Figure 5. These waves are propagating oscillations that carry energy and momentum across vast distances in the ocean. Understanding their characteristics is essential for harnessing their power effectively.

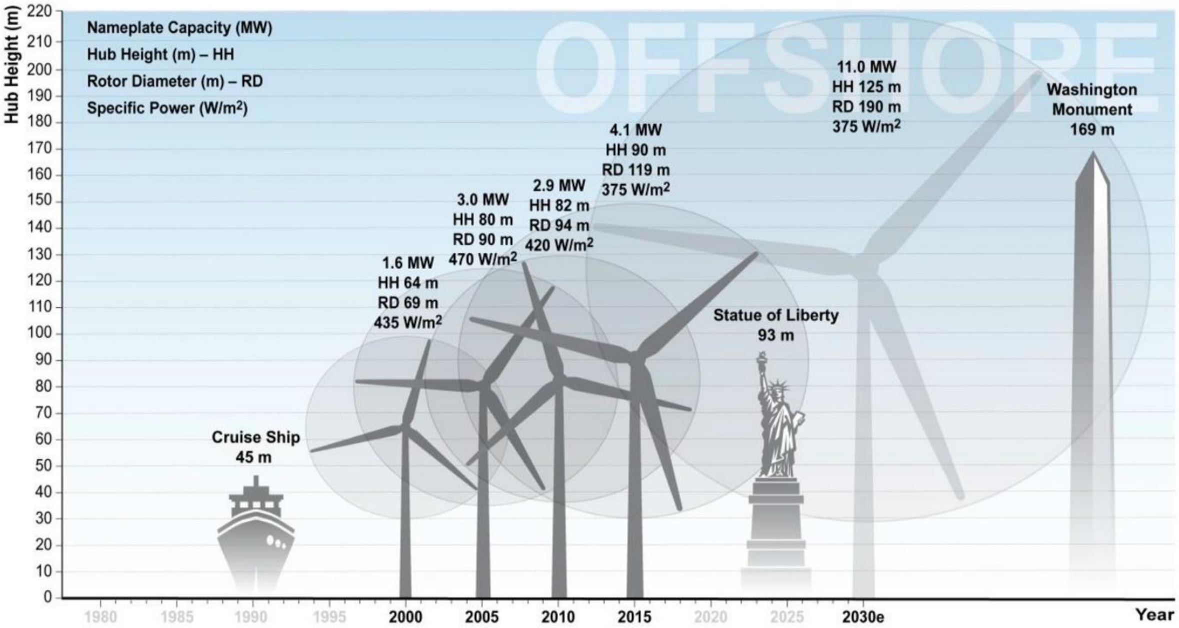

Figure 5: Ocean Waves Play a Crucial Role in the Marine Environment

5.1. Wave Formation and Propagation

Most ocean waves are generated directly or indirectly by wind blowing across the sea surface. As wind interacts with the water, it creates disturbances that steadily build, causing the wave crest to rise. The growth of wind waves is a complex process that is not fully understood, but it depends on factors such as wind speed, duration, and fetch (the distance over which the wind blows).

Wind-generated waves, also known as wind waves, have periods ranging from a fraction of a second to tens of seconds. These waves can travel thousands of kilometers beyond their area of generation, carrying energy across vast ocean expanses. When waves propagate away from their point of origin, they are referred to as swell.

5.2. Wave Energy Distribution

The energy contained in ocean waves is substantial and represents a promising renewable resource. The wave energy density per unit horizontal area varies across the globe, with the highest values typically found between latitudes 40° and 60° in both hemispheres. According to recent studies using ERA5 and European Space Agency Climate Change Initiative for Sea State data, the maximum mean wave power in the global ocean is approximately 119 kW/m, located in the Southern Hemisphere.

Wave energy distribution exhibits significant spatial variability. The most energetic coastal regions are found in the southwestern parts of South America, South Africa, and the southern coast of Australia. In the Northern Hemisphere, the North Atlantic stands out as the most energetic zone, with peak values around 80 kW/m. Along coastlines, the highest wave power values are observed on the western sides of Europe and North America.

5.3. Seasonal and Geographical Variations

Ocean waves display notable seasonal and geographical variations in their characteristics. In both the Northern and Southern Hemispheres, wave heights typically follow a sinusoidal annual cycle. Larger significant wave heights (SWH) occur in winter due to seasonal changes in high-latitude storm patterns that generate equatorward propagating swell.

However, some regions deviate from this hemispheric-scale seasonal pattern. For instance, the California coastal region experiences local wind events in boreal spring and summer, leading to a wind speed annual cycle with a distinct maximum in boreal spring and a corresponding local response in SWH. These areas: are called seasonal wind anomaly regions (SWARs) and are distinguished by the wind speed annual cycles that reach their maximum in late spring, the summer or the early autumn.

The degree of the deviation from SWH annual cycle depends on the swell exposure and nature of the wave field inside the region. Northern Hemisphere SWARs have the local winds with more identified effects because the winds have the greater seasonality when compared to that of the Southern Hemisphere.

Knowledge of these seasonal and geographical differences of the ocean wave parameters is vital for the effective design and deployment of wave energy provisions and better estimations of wind-wave conditions. It helps in the understanding of Marine Engineering, transportation and in the designing of wave energy conversion systems.

VI. Wave Energy Converter Technologies

A wave energy converter (WEC) is a device that seeks to capture the kinetic and potential energy of waves and convert it to mechanical or electricity. Most of these technologies have received a lot of focus due to their potential in providing clean and renewable energy with several uses including electricity generation and as motive power for ocean transportation vehicles, and desalination of seawater among others.

6.1. Point Absorbers and Attenuators

In the marine energy context, point absorbers are one of the most commonly encountered design archetypes. The structures are basically small, with a minimum horizontal component relative to their vertical profile, developed based on wave action at a single location. In a typical point absorber design, one end remains fixed relative to the water's surface while the other moves vertically with the wave motion. This reciprocating action drives a pump or linear generator to produce usable power.

Attenuators, another type of WEC, are oriented parallel to the direction of wave travel. Often modular in design, they rely on the flexing of joints to generate power. An example of this type is the Pelamis, manufactured by Pelamis Wave Power. This semi-submerged, articulated structure consists of cylindrical sections connected by hinged joints. The wave-induced motion of these joints is resisted by hydraulic rams, which pump high-pressure fluid to drive hydraulic motors and, in turn, power electrical generators.

6.2. Oscillating Water Columns

Oscillating Water Columns (OWCs) typically feature an 'L' shape at the water's surface. In this design, air is trapped in a chamber between the water's surface and a bi-directional air turbine mounted on top of the platform. As waves pass underneath, their reciprocating motion acts like a piston on the air in the chamber, raising and lowering the pressure.

When a wave crest arrives, it raises the water level, compressing the air and forcing it through the turbine. Conversely, as the water level drops with the wave trough, it creates a slight vacuum within the chamber, drawing air from the outside through the turbine. Although the turbine blades on either end may spin in opposite directions, the main shaft rotates in one direction, driving a generator to produce electricity.

6.3. Overtopping Devices

Overtopping devices, sometimes called terminators, utilize potential energy differences by raising water above the ocean's surface. These devices mimic the natural wave action found on beaches. Floating outstretched arms focus incoming waves, causing them to build in height as they approach an artificial 'beach' at the center of the device.

When waves crash on to this manmade beach, they surge up an inclined plane and into a storage tank positioned at a higher altitude in regard to the sea. The collected water is then allowed to flow down under the force of gravity and the flow that is produced is used to turn a turbine and hence produce electricity.

The following are some of the WEC technologies: WEC technology, advantages and challenges All the above technologies of harnessing wave energy have their different advantages and challenges. With further advancements in research and development in this field, these devices as being customized and fine tuned for sea conditions ranging from low energy seas for a wider range of application and better performance in different types of seas.

VII. Synergistic Wind-Wave Energy Systems

Findings have highlighted the blending of wind and wave energy technologies as the most effective technique of raising renewable energy capacity and lowering costs. This kind of cooperation means useful applications in breNT:ing, sharing of facilities, cost, and even the generation of electricity due to the collaboration between BETWEEN wind and waves.

7.1. Offshore Wind Appliances Joined with Wave Energy Systems

Although the integration of floating wind turbines and wave energy converters (WECs) still pose certain degrees of challenge, it is a huge improvement in the field of offshore renewable energy systems shown in Figure 6. Surge energy can also be exploited together with wind energy in the same area hence optimally utilizing available marine resources. Two primary integration methods have been identified:

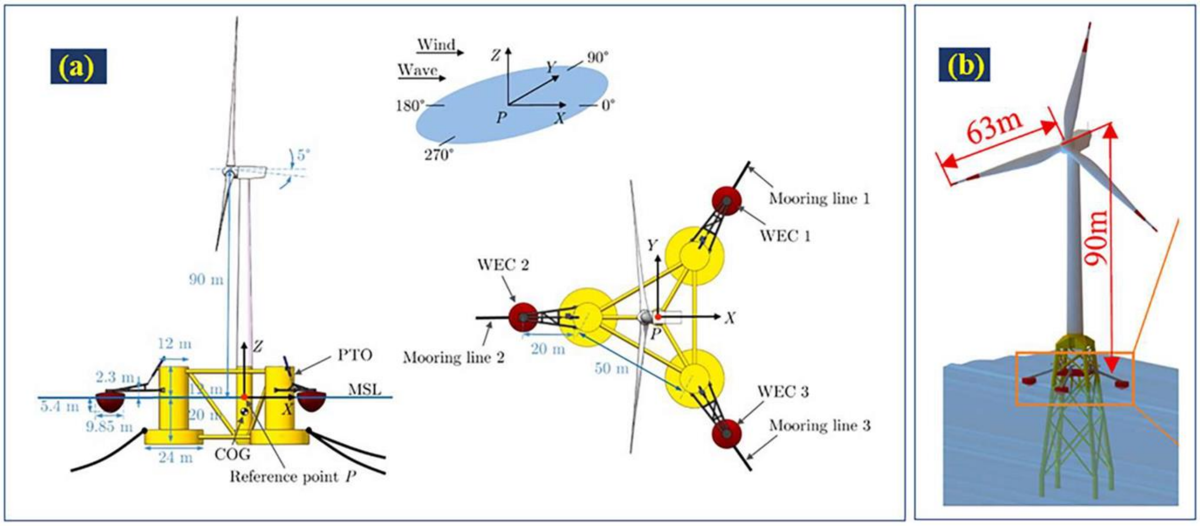

Figure 6: Wave Energy Converters (WECs)

1. Individual megawatt-scale WECs placed in clusters between floating wind turbines.
2. Numerous wave devices mounted on versatile floating platforms similar to wind turbine substructures.

These integration strategies enable the sharing of supply chains and manufacturing processes, potentially reducing overall costs and increasing efficiency.

7.2. Shared Infrastructure Benefits

Sharing infrastructure, services, and supply chains between wind and wave energy projects has a substantial impact on the levelized cost of energy (LCOE). Recent research commissioned by Wave Energy Scotland (WES) has revealed significant cost reduction potential:

	Technology LCOE Reduction
Wind Energy	Up to 7%
Wave Energy	Up to 40%
Combined Project	Up to 12%

These cost reductions are achievable without the need for fully hybrid wind/wave platforms, which are currently considered high-risk by most stakeholders. The shared infrastructure approach offers a more practical and immediately implementable solution.

7.3. Combined Power Output Optimization

The integration of wind and wave energy systems has the potential to smooth the renewables generation profile, addressing one of the key challenges of intermittent renewable energy sources. By combining these two technologies, the overall power output can be optimized to provide a more consistent and reliable energy supply.

This combined approach also has the possibility of providing greater growth of local content of projects, and assist the creation of a world-class wave energy industry. It has relation to the European Commission's Strategic Energy Technology (SET) Plan objectives to support other energy policy objectives.

Apart from cost benefits, benefits of the key players of Scottish wind energy and the waves include. Such benefits are technical and socioeconomic gain together with possible improvement of the national energy security in view of the more diverse generation sources. These integrated systems with the combination of wind and wave technologies can at the same time give a more efficient and reliable source of renewable energy.

In the future as research and development of this field is pursued the synergistic wind-wave energy systems are likely to assume a significant role in the shift towards a sustainable energy regime. The prospect of costs being cut, efficiency of energy being increased and more benefits to local economy has made this approach as beneficial to policymakers, energy companies or investors.

VIII. Environmental Considerations

The placement of Wind turbines and wave energy converters into the marine ecosystem has its benefits as well as problems. While enhancing these technologies, managing and reducing environment effects have emerged as the major concern among researchers, developers, and policymakers.

Three specific concerns for Aesthetics/Visual Impact, Noise/Particularly as well as Health of residents have been outlined to reflect the negative effects of wind turbines.

Turbine structures are extensive which create a great impact on the acoustic and visual environment. Research has revealed that these factors impact on the prices of similar properties in the surrounding residential estates. The disamenity or aesthetic eyesore generated by wind turbines has been postulated to significantly contribute to visual pollution and has been valued quantitatively at about 3. This was about fifteen percent of the price at which the house was sold from the residents. The impact of noise pollution is even higher and it goes as high as 7% of the sale price of affected cars relying on the amount of noise being produced.

However, there is more than the aesthetic concern involved with the establishment of wind turbines for generating electricity. They can make an area seem more ‘civilised’ and less ‘rural’, which in turn may ruin the aesthetics of the area under consideration. Turbine blades are the attention of the moving object and disturbing the image of calmness in the rural area. Also, the sunlight reflection with the blades’ spinning and shadow flicker are other visual injuries produced by the blades.

Noise from wind turbines originates from three primary sources: the rotation of the blades around the tower, the cutting of air by the blades and the function of the turbine as a mechanical construction. This amount reduces the property value particularly in zones that fall under high revelation to the noise generated by turbines where it is predicted to shave 6%. 80 percent of the price of each house seven nine percent.

8.1. A Glance at the Impacts that Wave Energy Converters have on the Marine Environment

Consequences of WECs on their life and ecosystems become the question in the case of their use in the sea and ocean. they can span such effects as changes in the pattern of Movement of whales and other marine mammals, changes in the behavior of the electricity sensitive fish such as sharks and salmon, change in wave behavior and erosion of beaches.

Another factor that needs to be taken into consideration in the wave energy project is the level of noise that WECs make in producing the electricity. This anthropogenic noise can superimpose the marine soundscape hence might have negative effects on fishes. Different reactions are inflicted in many species on sound with some being attracted towards sound while others are repelled. At present, researchers are even trying to understand its normally occurring sound and such variation in signals.

The release of electromagnetic fields (EMF) from underwater cables is another aspect which may pose problems to marine life forms. Although the intensity of the EMF signal around these cables is expected to be very low, which may be difficult to measure, exposures and potential impacts on species such as rays, sharks and salmon which are known to be sensitive to electrical signal are of interest.

The presence of WEC infrastructure on the seafloors also has implications on the alteration of marine habitats. The anchoring foundations can begin to serve purposes of artificial reef structures, draw fishes to it, and thereby change ecosystems. Concentration of marine creatures around WEC structures may have positive as well as negative effects for the overall marine species and fishery resources.

8.2. T. E. Prendota, et al.: Hybrid Systems Life Cycle Assessment

Currently, efforts are made aiming at developing hybrid wind-wave energy systems, in this regard, it is important to depict lca of the systems in their totality. Again, such assessments should embrace the construction, the functioning, the sustaining and the final shutdown of these systems if warranted.

As in the case of many other potential effects which have been postulated and are being studied, there are many unknowns. Controversies still surround the power generation capability of systems, and whether all this power generated warrants the ecological price to pay. Further, there arises a question of what impact an extensive wave energy production would be on the marine ecosystem besides the small scale test plants already in existence.

As such, there is need for continual studies and surveillance. These include assessment of the environment before the solar system installation as the post-installation baseline studies will use as a benchmark. Therefore, from the findings of these studies, future wave energy devices will be designed and located in a manner that will not be very disruptive to the marine environments.

IX. Conclusion

In the field of wind turbine applications and wave energy new viable technologies have presented a viable opportunity in the exploitation of renewable energy. This synthesis evidently impacts power generation and concern on environment containing a superb infinite compared to other ways of utilizing natural resources. When developing these hybrid generation systems, the power produced is certainly improved but other factors that may be associated with the new systems include noise and light pollution and some impacts that may have negative implications on the aquatic life.

While conducting further researches in this field the idea of using new technologies has to be implemented together with caring for the environment. Research and LCA of these systems need to continue because the effects of these systems on marine organisms and coastal environments cannot be fully ascertained and abated for a long time. By countering these challenges, the renewable energy sector has the potential of coming up with better solutions that will act as a basis of proactively developing more sustainable energy systems in the future.

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