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Offshore Floating Wind Turbine

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Abstract- Offshore wind energy is more and more considered a favorable source renewable energy. High and constant wind speeds allow a stable very efficient power generation. Interest among industry and academia is increasing day by day to develop and commercialize floating wind turbine technology. Floating wind turbine may offer a viable solution towards achieving large energy generation from renewable energy sources. It is very sure that this technology would in future offer large possibility for utilizing wind energy in deep water with cost effectiveness. A floating wind turbine with tower structure includes at least one stability arm to sea floor with rotatable position retention device that facilitates deep water installation. Buoyancy chambers are proving the variable buoyancy and are integral to tower and stability arm. Pump facilitates adjustable buoyancy as an aid in system transport, installation, repair and removal the rotor of wind turbine is located downwind of the tower structure to follow the wind direction by eliminating an active yaw drive system. The support tower and stability arm structure is designed to neutralize tension with buoyancy, gravity and possible wind forces. In this way top of the support tower leans downwind, provides a large clearance between the support tower and the rotor blade tips. This large clearance provides the use of articulated rotor hubs to minimize damaging structural dynamic loads and major component of turbine can assembled at shore and transported to an offshore installation site.

Index Terms- offshore floating wind turbine, floating foundations aerodynamics of floating wind turbines, MATLAB program for analysis

1. WIND TURBINE

Non-renewable resources such as coal, natural gas, oil, and nuclear power are the primary energy sources for most parts of the world. Burning fossil fuels, however, is harmful to the environment and fossil fuel supplies are limited and subject to price volatility. And the safe disposal of radioactive waste, the potential for radioactive contamination from accidents or damage and the threat of nuclear explosion are serious challenges to the success of nuclear power. Renewable resources such as wind, is a clean, renewable energy source. Wind's eco-friendly power can help to reduce the environmental loss. Following are some important properties for today's energy need: Eco-friendly, cost-effectiveness, mobility of the power station (Ex. In Rural areas, Sea, Desert, etc.), Efficiency of the power station, Low installation cost, running cost and maintenance [1]

Power available in wind per unit area,

$$\frac{P_{wind}}{A_1} = \frac{1}{2}\rho V_{wind}^3 \quad (w/m^2)$$

This indicates that power available in wind is proportional to the cube of wind speed. Assuming a typical value of wind density (ρ) at ⟦15⟧^°C at sea level to be 1.2 kg/m^3, power available in moderate wind of 10m/s is 600 W/m^2.

2. OFFSHORE WIND POWER

Offshore wind power utilizes the vast wind energy resources found offshore to produce electricity. More accurate wind data collection shows that most of the wind resources lie off the coast. It is this abundance of offshore wind resources that has brought an increased interest in the development of electricity-generating facilities in open sea water. As wind fluctuates with time, it is necessary to know about the continue supply than the total amount of energy available in a year. For electric power generation, minimum average wind speed required is 5m/s. No generation is possible if wind speed is too low and also too high. Best sites are those where favorable winds (with speeds 5-25m/s) are available for most of the time [1].

Offshore wind speeds are greater than coastal wind speeds at sea level. Ten kilometers from the shore, speeds may be 25% higher than at the coast and there are large areas of Baltic and North Sea with wind speeds above 8 m/s (at 50m). Offshore winds are less turbulent than onshore winds, and wind shear is also less. As the roughness of the sea increases with wind speed (as wave heights increase), so shear and turbulence slowly rise with wind speed above about 10 m/s.

3. FLOATING WIND TURBINE

A floating wind turbine is a wind turbine fixed on a floating structure that permits the turbine to generate electricity in deep water where bottom-mounted towers are not feasible. The wind can be uniform and steadier over water due to the absence of topographic features that may disrupt wind flow. The electricity generated is transferred to shore through undersea cables. The initial capital cost of floating turbines is competitive with bottom-mounted, near-shore rate of energy generation is higher because in the sea as the wind flow is often more steady and unobstructed by terrain features. There location of wind farms into the sea can decrease visual pollution if the windmills are located more than 12 miles (19 km) offshore, provide better accommodation of fishing and shipping lanes, and allows sitting near heavily developed seaside cities.

3.1 Power vs. wind speed characteristics

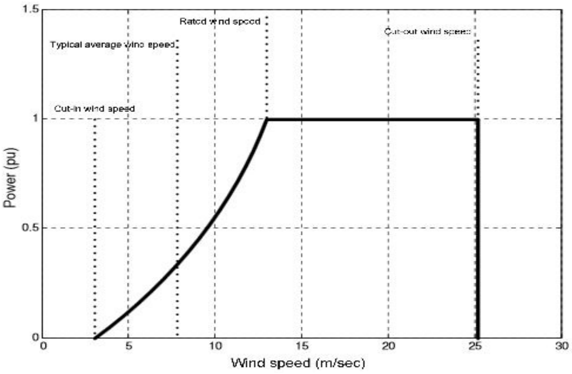

Figure 1: Power vs. wind speed characteristics. [1]

Most wind turbines start generating electricity at wind speeds of around 3-4 meters per second (m/s), generate maximum 'rated' power at around 15 m/s and shutdown to prevent storm damage at 25 m/s or above (as shown in figure 1).

4. AERODYNAMICS OF FLOATING WIND TURBINE

From a physical point of view, the static characteristics of a wind turbine rotor can be described by the relationships between the total power in the wind and the mechanical power of the wind turbine. These relationships are readily described starting with the arriving wind in the rotor swept area. It can be shown that the kinetic energy of air by rotor radius R travelling with wind speed V_{wind} corresponds to a total wind power P_{wind} within the rotor swept area of the wind turbine. This power, P_{wind}, can be expressed by:

$$P_{wind} = \left(\frac{1}{2}\rho_{air}\right) \times (\pi R^2) \times V_{wind}^3$$

Where,

ρ_{air} =air density (1.225 kg/m^3)
R = Rotor radius (m)
V_{wind} = wind speed (m/s)

It is not possible to extract all the kinetic energy of the wind, since this would mean that the air would stand still directly behind the wind turbine. The wind speed is only reduced by the wind turbine, which thus extracts a fraction of the power in the wind. This fraction is determined by the power efficiency co-efficient, C_p, of the wind turbine. The mechanical power, P_{mech}, in terms of C_p, and total power in the wind, P_{wind} using the following equation:

$$P_{mech} = C_p \times P_{wind}$$

However, it is theoretically possible to extract approximately 59% of the kinetic energy of the wind. This is known as Beltz's limit. Optimum C_p value lies between 0.52-0.55 for modern three-bladed wind turbines when measured at the hub of the turbine. Mechanical power, P_{mech}, that is extracted from the wind will depend on rotational speed, wind speed and blade angle, β. Therefore, P_{mech} and hence also C_p must be expected to be functions of these quantities. That is,

$$P_{mech} = f_{P_{mech}}(\omega_{turb}, V_{wind}, \beta)$$

From the simple geometric considerations, which ignore the wind turbulence created by the blade tip shows that the angle of incidence ϕ is determined by the arriving wind velocity V_{wind} and the speed of the blade. The blade tip is moving with speed v_{tip}, equal to $\omega_{turb} R$.

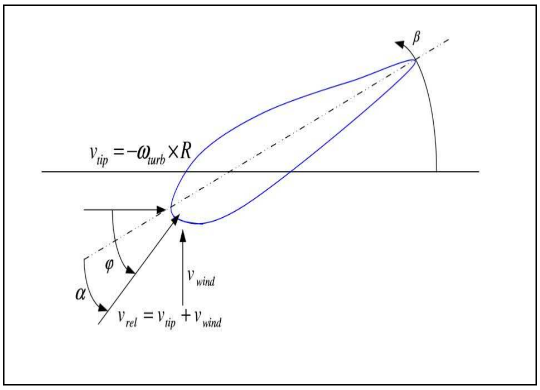

Figure No. 2: Blade element velocities and forces

Another commonly used term in the aerodynamics of the wind turbines is the tip-speed ratio, λ, which is defined by,

$$\lambda = \frac{\omega_{turb}R}{V_{wind}}$$

The highest values of C_p are typically obtained for λ values in the range around 8-9. This means that the angle between the relative air speed-as seen from the blade tip-and the most rotor plane is rather a sharp angle. Therefore, the angle of incidence ϕ can be calculated as:

$$\phi = \tan^{-1}\left(\frac{1}{\lambda}\right)\tan^{-1}\left(\frac{V_{wind}}{\omega_{turb}R}\right)$$

It is possible to adjust the pitch angle β of the entire blade through a servo mechanism. If the blade is turned, the angle of attack α between the blade and relative wind v_{rel} will be changed accordingly. So the energy extraction will depend on the angle of attack α between the moving rotor blades and the relative wind speed v_{rel} as seen from the moving blades. It follows that, C_p can be expressed as a function of λ and β.

$$C_p = f_{C_p}(\lambda, \beta)$$

is a highly non-linear power function of λ and β. Now, if the $C_p - \lambda$ curve is known for a specific wind turbine with a turbine rotor radius R it is easy to construct the curve of C_p against the rotational speed for any wind speed, V_{wind} Therefore, the optimal operational point of the wind turbine at a given wind speed V_{wind} is determined by tracking the rotor speed to the point λ_{opt}. The optimal turbine rotor speed is,[4]

$$(\omega_{turb})_{opt} = \frac{\lambda_{opt}V_{wind}}{R}$$

1.1. *Motions of floating wind turbine*

Wind turbine with floating platform system is assumed to undergo rigid body motions in the standard modes of motion that are considered in wave-body interaction theory, translational and rotational motions along the x, **y,** and z axes. Translational modes are surge, sway, and heave and represented translation along the x, **y,** and z axes respectively. Rotational modes are roll, pitch, and yaw and represented rotation along the x, **y,** and z axes respectively. [4]

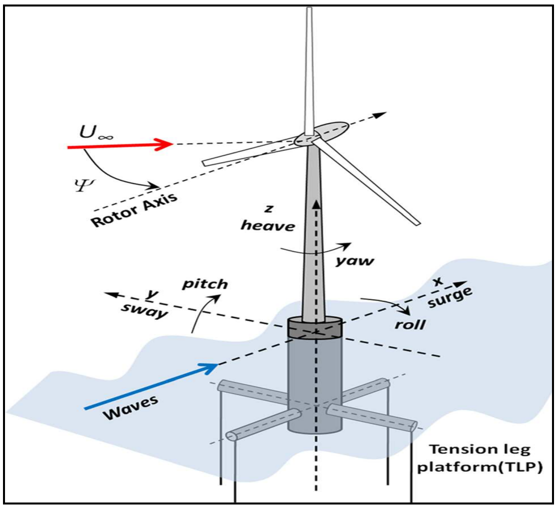

Figure No. 3: Degrees of freedom of FWT

5. TYPES OF FLOATING FOUNDATION

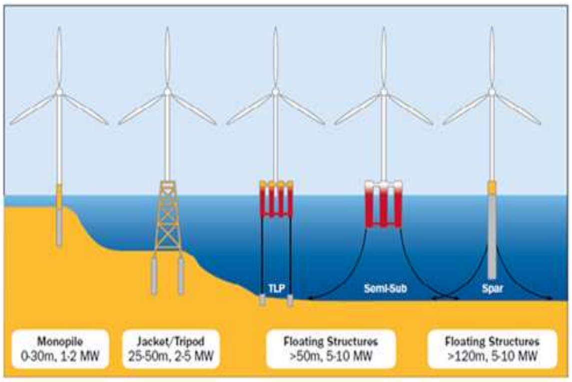

Figure No.4: Types of floating foundations

5.1. Spar-Buoys

The spar-type floater has a low water plane area that minimizes wave induced loading, and a simple structure that minimizes production cost. It can be used with any qualified offshore wind turbine. The mooring system is made of three mooring lines connected to the body by means of tethers that prevent excessive rotation about the vertical axis (yaw motion).

5.2. Semi-Submersible

Semi-submersible floater fitted with patented water entrapment (heave) plates at the base of each column. The plate improves the motion performance of the system significantly due to damping and turbulent water effects. This stability performance allows for the use of existing commercial wind turbine technology. In addition, floater's closed loop hull trim system mitigates average wind induced thrust forces. This secondary system confirms optimal energy conversion efficiency.

5.3. Tension-Leg Platform (TLP)

A Tension-Leg Platform (TLP) is a integrating proven TLP technology. It is widely used in the offshore oil and gas industry, and is being adapted for the offshore wind industry. PelaStar's features include:
- Simplicity of design – an optimized steel structure with no mechanical systems.
- Minimal motions and accelerations at the turbine – there are no pitch, roll, or heave that degrades performance and increases wear on components.
- Efficient quayside assembly, turbine testing, and partial commissioning reduces offshore work, weather delays, and the need for expensive offshore equipment. [6]

6. CASE STUDY

- Spar-Buoys

Table No. 1: Case Study

Design name	Hywind
Company	Statoil
Manufacturer	Siemens
Types of floater	Spar-buoy
Turbine capacity	2.3 MW (Prototype) 3-7 MW(Commercial)
Prototype installed	2009, west coast of Norway.

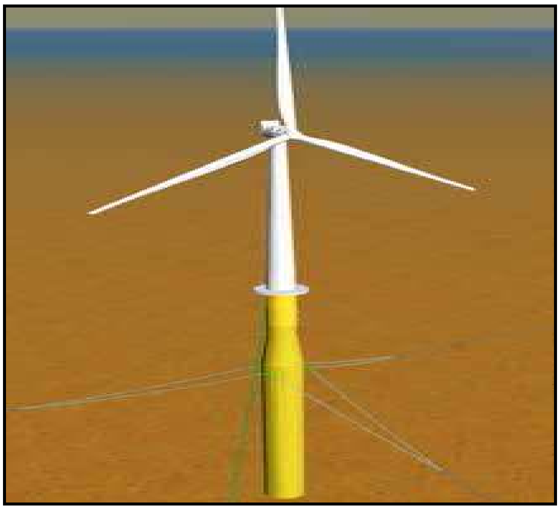

Figure No.5: Spar-Buoys

7. MATLAB PROGRAM FOR FLOATING WIND TURBINE

Matlab Coding:-

```
v=input('Enter the wind velocity = ');
r=input('Enter the radius of rotor = ');
d=input('Enter the density of air = ');
n=input('Enter the efficincy of turbine = ');
lambda = input('Enter the tip speed ratio = ');
w=(lambda*v)/r;
aoi=atan(v/(w*r));
p=(1/2)*d*pi*r^2*v^3;
pm=(1/2)*d*pi*r^2*v^3*n;
cp=pm/p;
fprintf('\n The power output =%f',p)
```

Table No. 2: Power output for different wind velocity

Sr. No	(v) m/s	(r) M	(δ) Kg/m^3	(η)	(λ)	Power Output KW
1	7	1	1.225	0.45	7	660.009347
2	7.5	1	1.225	0.45	7	811.782633
3	8	1	1.225	0.45	7	985.203456
4	8.5	1	1.225	0.45	7	1181.714985
5	9	1	1.225	0.45	7	1402.760390

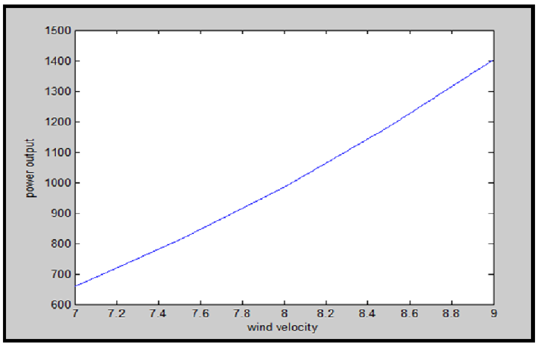

Figure No. 6: Power output vs wind velocity

Table No. 3: Power output for different rotor radius

Sr. No	(v) m/s	(r) m	(δ) Kg/m^3	(η)	(λ)	Power Output KW
1	8	1	1.225	0.45	7	985.203456
2	8	1.25	1.225	0.45	7	1539.38040
3	8	1.50	1.225	0.45	7	2216.70777
4	8	1.75	1.225	0.45	7	3017.18558
5	8	2	1.225	0.45	7	3940.81382

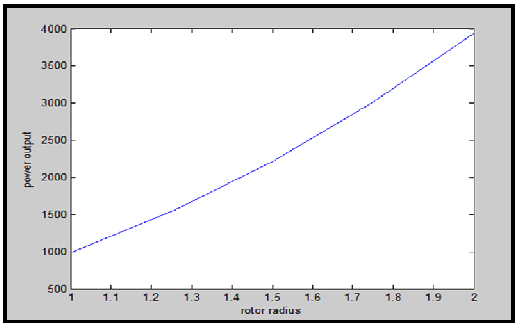

Figure No.7: Power output vs rotor radius

V = Velocity (m/s)
r = Rotor Radius (m)
δ = Air Density (Kg/m^3)
η = Mechanical Efficiency (%)
λ = Tip Speed Ratio

7. ADVANTAGES *OF FWT*

- The first and most important fascinating advantage of offshore wind is easy access and strong wind resource over deep waters.
- Offshore wind minimizes the distance from generation to load centers, without utilizing a valuable land.
- Generally wind turbines negatively impact the skyline (visual pollution) or result in disturbing noise. Floating turbines replaced these concerns by allowing wind farms to be pushed farther offshore and out of sight.
- There are also several manufacturing advantages to floating platforms, such as using less material in construction and reducing the need for specialty in marine engineering expertise.

7.1 Challenges of Floating Wind Turbine

- The engineering challenges are extremely complex and many of the concepts have yet to be carefully tested.
- Various early stage computer models attempt to predict turbine performance with varying degrees of success.
- Prototypes are gathering valuable data to drive further design modification, but the longest has been operational for only three years so the actual realistic lifetime of a floating wind turbine is still unknown.

8. CONCLUSION

Floating wind turbines have potential to unlock huge offshore wind energy resources in a cost effective manner, but many concepts must be proven before this industry can scale. Currently the market for floating offshore wind is very uneven and there is not yet a clear design winner. Considerable investment will be needed for this technology to scale and also strategic partnerships with larger energy companies. Floating wind turbines are still years from mass deployment but they offer a lot of promise as the next step change in the wind energy industry. Wind power struggles to be economically competitive with fossil fuel generation and floating wind turbines may be a crucial component to this effort.

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