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Optimum Location of the Offshore Wind Turbine Along Western Coastal Line of India

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Abstract: ***a study has been carried out to locate the offshore wind turbine along the western coastal of India and the power generation at each selected site has been determined. This paper gives an overview of the most optimum location for the installation of offshore wind turbine along the western coastal line based on the bathymetry study, wind and wave characteristics and the power produced by an individual wind turbine subjected to the selected site condition.***

Keywords: Monopile, Wind turbine, Rotor, Nacelle, Hub height

I. INTRODUCTION

Due to the increase in population and the reduction in the availability of fossil fuel resources, an alternate source of energy has to be discovered. Out of the variety of sources of renewable energy available, wind energy has gained more attention. As a result of this many efforts have been put forward to design and built wind turbines .Each of these wind turbines that are designed can be used individually or as a series of turbines and are called wind farm.

The offshore wind energy is the use of the wind farms that are constructed usually on the water bodies such as in the ocean on the continental shelf which in turn harvest wind energy and generated electricity. From the studies it was found that the wind speeds are higher at offshore than onshore. So the electricity generation is eventually higher per amount of capacity installed for the offshore wind turbines.

The wind turbines are available in two types, they are Horizontal axis wind turbines (HAWT) and Vertical axis wind turbines (VAWT).The HAWTs designs that are existing are more efficient for the production of power on a larger scale when compared to the available VAWT designs. The VAWT of smaller size are more apt for urban areas and can be used for producing small-scale wind –energy generation.

This paper focuses on the location of offshore wind turbine along the western coastal line of India. The bathymetry studies showed that western parts are comparatively shallow and they have a large area in lower depth for supporting the wind turbines than the eastern coast [1]. Also the wind speed is higher in western coast than the eastern coast. Four sites have been selected along the western coastal line and the most optimum location has been chosen. The data analysis was carried out based on the load and the wind characteristics at various locations. The forces acting on the support structure are wind loads, wave loads, current loads, turbine loads etc. were determined.

The most optimum location is one where the wind turbine at a lower height generates more energy, thus reducing the overall cost of the structure.

In this paper, analysis of the wind turbine having Monopile foundation is done, as the Monopile foundations were considered to a depth of 25m and the depth of ocean up to 25m from the shore has been considered [2] .In the further studies ,ocean depth greater than 20m can be done.

II. LITERATURE REVIEW

Kothari et al (2016) [3], this paper presents that the offshore wind energy has increased from 3GW to 80 GW in 2015.For setting up of the wind farm, a wind speed of about 6.5 m/s is required. From the studies from this paper shows that coastal areas of Tamilnadu and Gujarat may have potential for offshore wind power generation. **Mani Murali et al (2010)** [1] presents that the water depth of the sea plays an important role in site selection as it decides the cost of the installation of the wind turbine tower. Therefore practical depth for turbine installation is about 15-75m.**Sanil Kumar et al (2011)** [4]**,** this paper presents that the oceanography of the Indian coastal region is dominated by three seasons, viz. southwest monsoon, northeast monsoon and fair weather period. **Sanjeev Malhotra et al (2015)** [5]**,** in this paper its says that the factors that govern the site selection of the wind farm include site availability, visibility and the distance from the shore etc.

III. METHODOLOGY

First the location for setting up the wind farm is identified based on the Bathymetry study. The load analysis was carried out for the wind force, wave force, current force and the turbine at the desired locations. Offshore wind turbine is located for more power generation. Then power generation capacities of each turbine at the selected sites were determined.

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IV. PRELIMINARY DESIGN

3.1 Site selection

One of the important processes in the preliminary stage of a design process is the site selection. Some of the sites in India are protected by law; these sites cannot be selected for setting up the wind turbines. These protected sites include fisheries reserve, areas of archeological interest etc. The factors that govern the site selection are the site availability, the distance from the shore to the wind farm, distance to the local electricity generation distribution companies etc. The sites that are selected for setting up the wind farm are;

- Trivandrum
- Cochin
- Calicut
- Kanyakumari

3.2 Data required

For the optimization of the location the following data have been collected

- Turbine characteristics
- Wind characteristics
- Wave characteristics

3.2.1 Turbine characteristics

The turbine details for the optimization have been taken from a typical NREL Phase IV 5 MW wind turbine as indicated table.1

Table.1 Wind turbine properties

Sl.No	Properties	5MW OWT
1.	Rotor diameter	126m
2.	Rotor Nacelle mass	350000kg
3.	Water depth	20m
4.	No. Blades	3
5.	Hub height	50m
6.	Top diameter of the tower	3m
7.	Bottom diameter of the tower	5m
6.	Rotor Orientation	Upwind

3.2.2 Wind characteristics

The wind turbine generates electricity by driving the generator by the power of the wind. Since the wind is a clean and a renewable fuel source from the sun it does not run out. A wind speed of min 3-4 m/s is required to rotate the wind turbine. The wind data required for the calculation observed from the following map given below in figure.1 (Indian National Centre for Ocean Information Services (INCOIS), Government of India).The wind speed at various heights for the selected locations is determined by extrapolating and is given in the table.2.

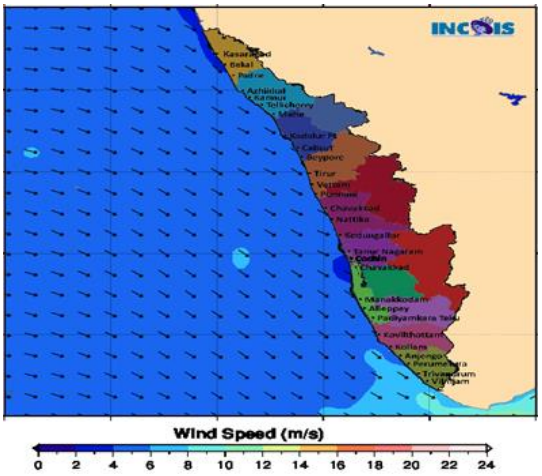

Figure.1 Wind speed profile

Table.2 Wind speed data

Height from the mean sea level	Wind speed (m/s)			
	Trivandrum	Cochin	Calicut	Kanyakumari
10	6.5	4	6	10
20	6.92	4.26	6.38	10.64
30	7.16	4.41	6.61	11.02
40	7.33	4.51	6.77	11.28
50	7.47	4.59	6.89	11.49
60	7.58	4.66	6.99	11.66
70	7.67	4.72	7.08	11.8

The figure 2. below shows the comparison of the wind profile at various heights.

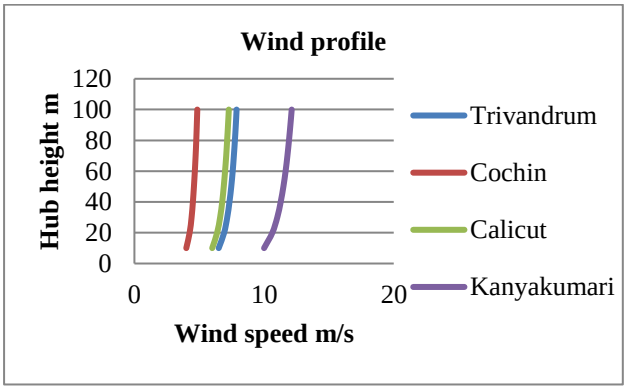

Figure.2 comparisons of wind profile

From figure.2, the hub height, of 90m has been considered, as the wind profile remains constant.

3.2.3 Wave data

When the wave force acts against the substructure, the lateral force acts near to the foundation. The wave load depends upon the wave height, wave period and the water depth. The wave heights for the selected locations were obtained from the following figure.3 given below.

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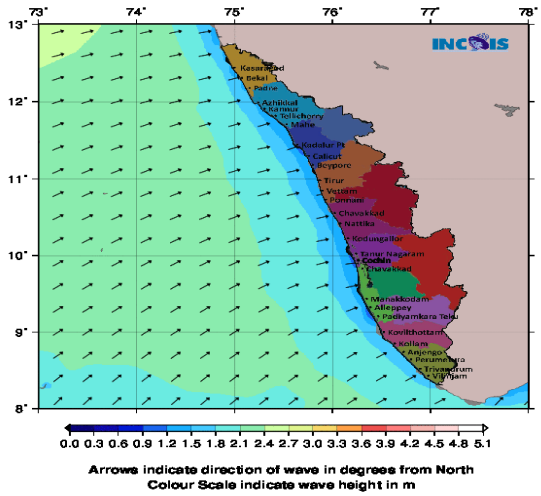

Figure.3 Wave heights

The corresponding wave heights for the selected sites are shown in the table.3.

Table.3 Wave height

Location	Wave Height (m)
Trivandrum	2.1
Cochin	0.9
Calicut	1.2
Kanyakumari	2.1

The corresponding wave period for the selected locations were determined for the wave heights given in table 3 by the equation (I) given below .The wave period at various locations were obtained in the table.4

Wave period: $11.1\times\sqrt{\frac{H_S}{g}}$ (I)

Table.5 Wave period

Location	Wave period (s)
Trivandrum	5.13
Cochin	3.36
Calicut	3.88
Kanyakumari	5.13

3.3 Bathymetry study

The bathymetry study was carried out to locate the offshore wind turbine at various sea depths at different location for determining the foundation required at different depths and to study the power generation. The bathymetry data obtained from NOVAA –National Centers for Environment Information Services are indicated in figure.4.

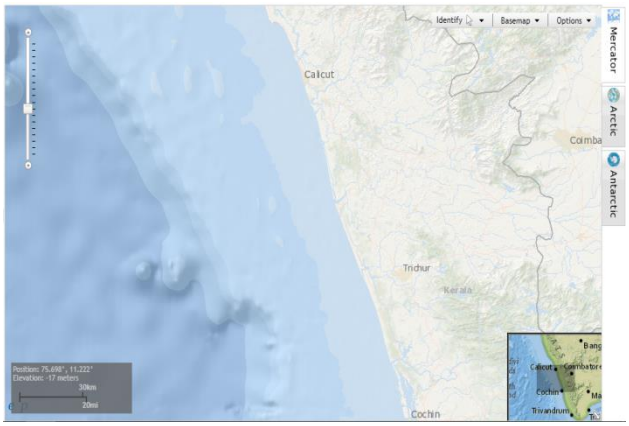

Figure.4 Bathymetry study

The table.5 to table.8 shows the bathymetry data for the selected sites like Trivandrum, Cochin, Calicut and Kanyakumari.

Table.5.Bathymetry study of Trivandrum

Latitude (E)	Longitude(N)	Depth of the ocean (m)
76.920°	8.439˚	20
76.913°	8.433˚	30
76.908°	8.428˚	40
76.833°	8.365˚	50
76.808°	8.337˚	60
76.74°	8.278˚	70
76.730°	8.261˚	80
76.702°	8.235˚	90
76.688°	8.224˚	100

Table.6 Bathymetry study of Cochin

Latitude (E)	Longitude(N)	Depth of the ocean (m)
76.121°	9.945˚	20
76.097°	9.923˚	30
76.003°	9.895˚	40
75.932°	9.874˚	50
75.870°	9.854˚	60
75.823°	9.826˚	70
75.786°	9.830˚	80
75.756°	9.818	90
75.744°	9.811˚	100

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Table.7 Bathymetry study of Calicut

Latitude (E)	Longitude(N)	Depth of the ocean (m)
75.667°	11.224˚	20
75.631°	11.211˚	30
75.499°	11.144˚	40
75.384°	11.074˚	50
75.299°	11.014˚	60
75.288°	11.009˚	70
75.280°	11.006˚	80
75.263°	11.003˚	90
75.238°	10.995˚	100

Table.8 Bathymetry study of Kanyakumari

Latitude (E)	Longitude(N)	Depth of the ocean (m)
75.667°	11.224˚	20
75.631°	11.211˚	30
75.499°	11.144˚	40
75.384°	11.074˚	50
75.299°	11.014˚	60
75.288°	11.009˚	70
75.280°	11.006˚	80
75.263°	11.003˚	90
75.238°	10.995˚	100

V. LOAD ANALYSIS

The loads that are acting on the offshore wind turbine include permanent load and Environmental load. Each of these loads acting on the offshore wind turbine is shown in the figure.5 below

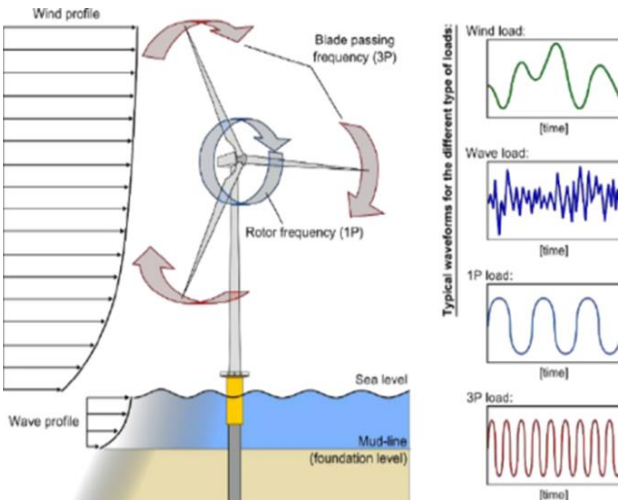

Figure.5 Loads acting on the wind turbine

4.1 Permanent Load

Permanent load acting on the wind turbine include the load of the rotor and nacelle that acts on the top of the tower as a lumped mass. The load of the transition piece and that of the tower acts on the monopile.The permanent loads were considered from the NREL Phase IV wind turbine is given;

- Rotor Nacelle mass – 3430kN
- Mass of transition piece and tower – 4064 kN

4.2 Environmental Load

The environmental loads that are acting on the offshore wind turbine depends upon the site conditions and also the force acting on the wind turbine. These loads will have a large amount of uncertainties. These loads acts on the wind turbines through a several load combinations.

VI. POWER GENERATION RESULTS

The power generation capacity of each wind turbine was determined by the equation (II).

Power of the wind turbine $P = \frac{1}{2}\rho AV^3$ (II)

Blade length = 52m

Amount of the power generated is based on the area swept by the turbine blades in sq. m

$$A = \pi r^2 = \pi \times 52^2 = 8495\ m^2$$

density of air ,Rho= 1.225 kg/cu m and the velocity of wind at that level in m/s. The table 9 gives the power generated at various heights for the selected location.

Table.9 Power generation at various heights

Height from mean sea level (m)	Power generation in MW			
	Trivandrum	Cochin	Calicut	Kanyakumari
40	2.04	0.477	1.61	7.466
50	2.16	0.503	1.70	7.89
60	2.26	0.526	1.77	8.24
70	2.34	0.547	1.84	8.59
75	2.38	0.555	1.87	8.68

The wind power generation at 75m and 40m hub height is higher at Kanyakumari .The other sites Trivandrum, Calicut and Cochin the power generation is decreasing respectively, as indicated in figure.6 the wind speed Increases the power generation increases..

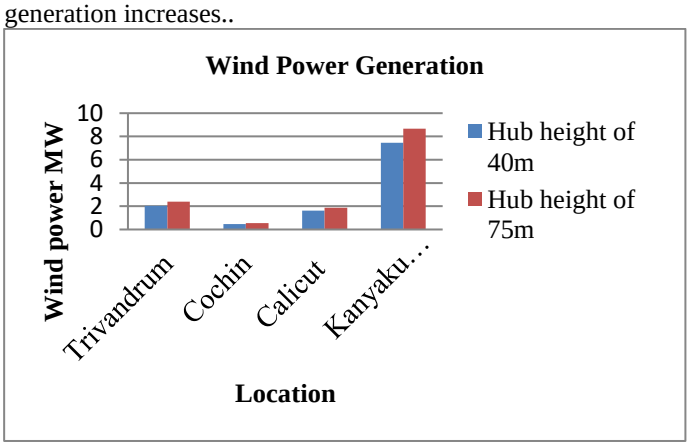

Figure.6 Power generation along western coastal line

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VII. CONCLUSIONS

The most effective location of the offshore wind turbine along the Kerala coastal line was identified. From the data analysis, the wind turbine at Kanyakumari produces the maximum power of 8.68 MW at the hub height of 75m when compared to the other selected sites. The energy generated at Kanyakumari is greater than 5MW even at the height of 40m. Hence the hub height can be reduced to 40m to generate more energy.The other selected sites produces power less than 3MW at a hub height of 75m,out of which Cochin produces the least, hence wind farm is required to produce more energy.

REFERENCES

1. R.Mani Murali, P.J.Vidya, Poonam Modi (2014) "Site slection for offshore wind farms along the Indian coast" ,*Indian Journal of Marine sciences,*Vol.43 pp *1-6.1*
2. John Corbett nicholson (2011) "Design of wind turbine and foundation systems :optimization approch,*IOWA Research online.*
3. Mr.Kothari ,Mr.Umashankar (2016)," OffShore Wind Energy in India" *Wind power*.
4. V. Sanil Kumar, K. C. Pathak, P. Pednekar,N. S. N. Raju and R. Gowthaman (2011), "Costal process along the Indian coastal line",*Current Science,*Vol 91.
5. Sanjeev Malhotra (2015) "Selection, Design and Construction of Offshore Wind Turbine Foundations ",*Wind turbine* ,pp. 231-264
6. Antoni Calderer, Xin Guo,Lian Shen, Fotis Sotiropoulos (2018), "Fluid –Structure interaction simulation of floating structures interacting with complex, large scale ocean waves and atmospheric turbulence with the application to floating offshore wind turbines", *Journal of Computational Physics*. Vol.355 , pp 144-157
7. Bazilevs Y., Korobenko A., Deng X., yan J., Kinzel M., Dabiri J.O (2015) "Fluid-structure interaction modeling of vertical axis wind turbine", *Journal of applied Mechanics*. Vol.81 pp 8-16
8. Kyoungsoo Lee, Ziaul Huque, Raghava Kommalapti, Sang –Eul Han (2017)" Fluid-Structure interaction analysis of NREL phase VI wind turbine: Aerodynamic force evaluation and structural analysis using FSI analysis", *Renewable energy*. Vol.113 pp 512- 531
9. Lin Wang ,Athanasios Kolios, Pierre-Luc Delafin, Takafumi Nishino, Theodore Bird (2015) "Fluid structure interaction modeling of a novel 10MW vertical axis wind turbine rotor based on computational fluid dynamics and finite elemental analysis", *Journal of fluids and structures*. Conference: EWEA 2015
10. Lin Wang, Robin Quant, Athanasios Kolios (2016) "Fluid structure interaction modeling of horizontal axis wind turbine blades based on CFD and FEA", *Wind energy*. Vol.158 pp 11-25
11. Ming-Chen,Yuri Bazilevs (2012) "Fluid –structure interaction modeling of wind turbines :Simulating the full machine", *Computational Mechanics* . Vol.50 pp 821-833
12. "Offshore wind", *Global Wind Energy Council* 3 May 2018.
13. Shayan Naderi, Sogand Paranehmasiha, Farschad Torabi (2018) "Modelling of horizontal axis wind turbine wakes in Horns Rev Offshore wind farm using an improved actuator disc model coupled with computational fluid dynamics", *Energy conversion and Management*. Vol. pp
14. Yan Zhang, Partha P.Sarkar,Hui Hu (2016) "An experimental investigation on the characteristics of fluid –structure interactions of a wind turbine model sited in microburst –like winds", *Journals of fluids and structures*. Vol.171 pp 953-968
15. Zhang J.P., Han Y., X.Zhou A., Hu D.M., Ren J.X. (2014) "Study on vibration of the offshore large –scale wind turbine blade under fluid structure interaction at different speeds", *Journal of vibro engineering*, Vol.16 pp 3236-3247
Indian National Centre for Ocean Information Services (INCOIS), Government of India Indian National Cen NOVAA- National Centres for Environmental Information Services