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Off-Shore Wind Energy Potential Assessment of Indian Coastlines using Various Scatterometer Data.

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ABSTRACT: Wind energy is one of the most economical and substantiate forms of renewable energy technologies universally to expedite the ever exponentially increasing electricity demands in a sustainable approach. Presently, India possesses a lot of onshore wind farms that in total accounts for the fifth largest country in terms of wind power capacity around the entire globe. The National Offshore Wind Policy (2015) of the Indian Government aims to harness and create the wind resources within the Exclusive Economic Zone or the EEZ. According to the strategy, a target of 60 Giga-Watt of power generation by the year 2022 has been aimed to be implemented from onshore and offshore wind farms combined. The classical or the traditional method of wind resource assessment is carried out by inspecting a big amount of in situ wind data and figures at variable altitudes. In Indian waters, there are some meteorological masts which are only limited to a few places. Satellite remote sensing helps in giving synoptic data due to the larger swaths and larger periods of acquisition. Microwave scatterometers are one of those, which basically provide satisfactory data for the whole planet. In this research paper, the offshore climatology of the Indian oceans i.e. the Bay of Bengal and the Arabian Sea is generated from a large collection of data of QuikSCAT, OSCAT and ASCAT scatterometers collaboratively. Scatterometer Equipments in general have been manufactured in a way that they could generate long-term synoptic monthly ways of wind vector assessment. Wind Power Density or the WPD is formulated here by using Weibull distribution parameters at an altitude of 10 m above the sea-level. The WPD, Power and the velocity of the wind vector all have been analysed at different altitudes above the sea-level using a set of logarithmic law and WPD scale and surface parameters for a few standard turbines of India working at different capacities and loads. The Annual potential of the wind energy has been thus formulated by considering the bathymetric changes with respect to several uncontrollable variables and the arrangement from the waters for all the coastal states which are the parts of Indian coast's EEZs.

KEYWORDS: Wind Energy · Renewable Resources · Off-Shore Wind Energy · Wind Energy of India · Scatterometer · Exclusive Economic Zone · Weibull distribution parameters

I. INTRODUCTION

Recent researches have shown that human generated greenhouse gases are responsible for causing havoc to the planet's climate system including oceans, land and ecosystems. Due to the ever-increasing awareness in the common public on the topic of environmental issues which are caused due to the overutilization of fossil fuels, many developing nations have primarily focussed on harnessing energies from renewable resources in a sustainable and substantial manner. Many nations have understood that the ever-increasing demands for electrical energy can only be fulfilled with the exploitation of the latest renewable resources of energy. India possesses the longest coastline of approximately 7600 km including all the islands and the national mainland. It has been on fore-front holding-up renewable energy development as a 'strategic source of energy' to implement indelible energy security for tomorrow. It stands the fifth rank in the total installed wind power capacity on the entire planet. However, this accounts only for the onshore wind farms available in the country. The current contribution of renewable energy stands at 57.2 Giga-Watts contributing around 17% of the overall installed capacity, which includes 32 Giga-Watt of wind power in the country as of March 2017. Accordingly, a target of 60 Giga-Watt power generation by 2022 has been aimed to extract from onshore as well as offshore wind farms. When compared to the net power generation from the onshore winds, the offshore power generation is a bit higher by around 3–4 times due to less surface roughness. Though, the monitoring of the wind resources using offshore

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meteorological masts is very hard, locational and costly. Classically, the sea wind energy potential for a specific location is used for the estimation from the collected data. Most frequent techniques involved are Sound Detection and Ranging or the SoDAR and Light Detection and Ranging or the LiDAR. Due to the limited access to these data, facts and figures, it is quite hard to compute the net wind energy from the oceans. Thus, the observation results are less accurate, less reliable but useful. Moreover, as the entire data is restricted to a specific location in the sea, it is not much viable to idealise the same for the entire ocean. Satellite remote sensing gives some sets of synoptic data over a large number of areas for a longer period of time. Here, The OSCAT data has been used to evaluate the off-shore wind power potential in India. The OSCAT or the Ocean Scatterometer was launched by The Indian Space Research Organisation in the year 2009 and it was used to provide the global wind vector dataset from 2010 to 2014. Currently, the ASCAT Scatterometer of the EUMETSAT (European Organization for the Exploitation of Meteorological Satellites) is providing all the global wind vector data.

II. DATA, METHODS AND FORMULATIONS

Microwave scatterometers are specific goal missions which are mainly created to compute the equivalent surface ocean wind vector across the planet. In this particular article, pass-wise scatterometer wind products at 0.125×0.125 degrees spatial resolution for the whole mission from 2000 to 2009 and from 2010 to 2014 respectively and for 2012–2016 have been processed to generate long-term monthly means in the entire Indian region (Latitude: 0–25°N; Longitude: 65–95°E). The selected wind vector precision and accuracy are 3.0 m/s for ASCAT, 0.5 m/s for QuikSCAT and OSCAT respectively. We can get a coverage frequency of wind at around six times/day. In order to minimise the uncertainty and to increase the sample-space,observations from various satellites were combined with different local equatorial cross-times. This increases the accuracy of the offshore wind resource estimations. The scatterometer data is thus not validated, and no improvements and corrections are done. The finalization was done by collecting sample-sets from each of the satellites using a 0.125° Grid-Web. The consideration is done only for those wind vectors that have satisfactory quality data flags without considering rain effects, contamination on the surface, etc. in the sample-space.

A twin-parameter Weibull Distribution Method (WDM) is used for research in this article. This distribution has been widely used for computation of wind energy density in many other regions such as Europe, Brazil, China, etc. The estimation of the probability density function of the WDM is done by,

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^{k}} \quad (1)$$

Here, the f(v) is the wind vector velocity probability for speed v, k is the shape parameter (dimensionless) and c is the scale parameter (m/s), k and c were determined using standard deviation method as follows:

$$k = \left[\sigma/\underline{v}\right]^{-1.087} \quad (2)$$

$$c = \underline{(v)}/\left[\Gamma\left(1+\frac{1}{k}\right)\right] \quad (3)$$

where $\underline{v}$, σ and Γ(x) are mean wind speed, standard deviation and gamma function, respectively
The potential of wind in a location can be evaluated using the wind power density equation based upon Weibull Probability density function:

$$E = \frac{1}{2}\rho c^{3}\Gamma(1+\frac{3}{k}) \quad (4)$$

ρ is the standard air density (=1.225 kg m−3) at sea level. As the scatterometer derived winds are at 10 m above the sea surface, the wind speeds at the hub height h are obtained via this formula:-

$$v_h = v_0\left(\frac{\log(h/z_0)}{\log(10/z_0)}\right) \quad (5)$$

where vo is the wind speed at height 10m above the sea level and zo is the roughness length typically equal to 0.0002 m at the sea surface. Using Weibull Probability Density Function, the shape parameter kh and scale parameter ch at desired height h were formulated using following equations and the computed wind energy density at height h:-

$$k_h = k_0\frac{\left(1-0.088\log\left(\frac{h_0}{10}\right)\right)}{\left(1-0.088\log\left(\frac{h}{10}\right)\right)} \quad (6)$$

$$c_h = c_0\left(\frac{h}{h_0}\right)^{n} \quad (7)$$

where n is called the power law coefficient and is expressed as:-

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$$n = \frac{(0.37 - 0.088 \log c_0)}{(1 - 0.088 \log\left(\frac{h}{10}\right))} \quad (8)$$

The power thus generated by a turbine is represented by the power curve which is generally formulated by the turbine manufacturer considering the flow mechanics passing through the turbine blades and the efficiency of the rotor/generator couple. There also exists a theoretical upper bound of power output. It is represented by $P_t = PAC_P$. Here, C_P is the Betz Limit of Efficiency or the maximum theoretical efficiency of a turbine rotor. The total electrical power output that can be generated by the wind turbine within the cut-in (vi) and the cut-out (vo) wind speed using the Weibull distribution function can be expressed as:-

$$E_t = \int_{v_i}^{v_o} P_t(v).f(v).dv \quad (9)$$

The capacity factor C_f, an important index of wind turbine electrical energy generation was formulated by $C_f = E_t/P_r$. The individual turbine footprint or the Array Spacing of the turbines was calculated using the following equation:-

$$\text{Array Spacing} = D^2 \times v_{df} \times v_{cf} \quad (10)$$

where D is the diameter of the turbine rotor, v_{df} and v_{cf} are the downwind and upwind spacing factors respectively. And finally the number of turbines commissioned within the area was determined using:-

$$\text{Number of Turbines} = \text{Total Area Available} / \text{Array Spacing} \quad (11)$$

Nameplate wind power or total installable capacity is formulated by multiplying the rated power of a single turbine with the maximum calculated number of installable turbines. But this is not achievable for any turbine due to several losses such as availability, scheduled maintenance, unplanned shutdown, wake effect, turbine efficiency, etc. Therefore, the practical power estimates were also computed using the power curve provided by the manufacturer.

III. RESULTS AND DISCUSSIONS

Bathymetry thus plays a very important role in choosing and finalizing the appropriate turbine foundation technology. Figure 1 shows bathymetry derived from the General Bathymetric Chart of the Oceans i.e. the GEBCO and different techniques used for various ranges of water depths within the EEZ of India. For example, the Monopile foundation is suitable for depths up to 35 m - 40 m and floating types of turbines are better for the depths that are greater than 100 meters. The water depth choices and the distance from the corresponding coast has a direct impact on the design, construction, maintenance of the infrastructure, cost of the installation process and obviously the cost of power production. At present, Monopile foundation is most practical economically. India is actually very much blessed as it possesses a vast 7517 km of coastal length including the mainland as well as the islands. It thus possesses a large continental shelf along the western coast and a slightly smaller shelf along the east coast.

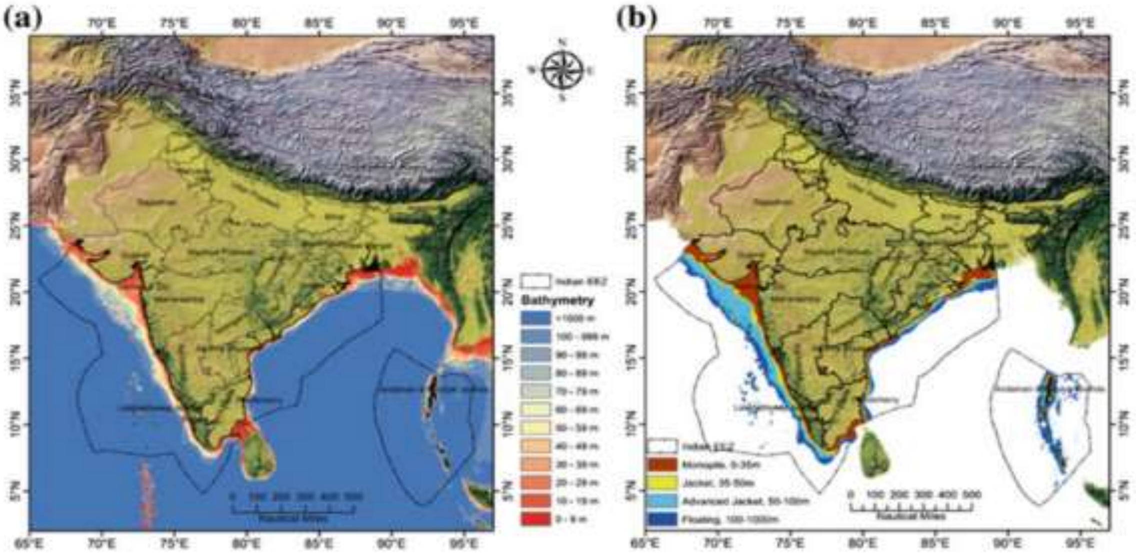

Figure 1 (a) GEBCO Seabed Topography **(b)** Turbine Foundation Technology within Indian EEZ

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Scatterometers usually give wind vector data at 10 m height above the sea level. This data is obviously extrapolated to the required height using logarithmic approach using Eq. 5. The winds are then averaged to get the monthly climatology and then monthly averaging to get annual average or annual mean. The monthly wind vectors show an intense variability of seasons owing to the Indian Summer Monsoon (ISM). Stronger winds here are observed from July to September possessing a speed of 10m/s to 12 m/s, most noticeably in the South-West Arabian Sea. During June–August, the Bay of Bengal Coastal Outline also shows higher wind speeds due to the monsoon depressions. Figure 2(a, b) represents an annual mean wind vector velocity within the Indian EEZ at 10 and 80 m respectively. The wind power density or the WPD at 10 meters was formulated using the Equations (2)–(4) of Weibull distribution method. However, WPD at the 80 meters height was computed using a scale and surface shape parameters following Equations (6) and (7) and then applying Equation (4). Figure 2(c, d) represents annual average wind vector power density within the required region of research. It shows that the wind speeds range between 5 m/s and 9 m/s along the Western Indian Coast at 10 meters and 80 meters. Winds in the eastern coasts are in the order 6 m/s and 9 m/s at 10meters and 80 meters. The lowest wind speeds mainly in between 3 m/s and 5 m/s are experienced in the south-western coasts along Goa, Karnataka, Kerala and Lakshadweep island coastlines, some parts of West Bengal Coast and also northern Andaman islands as shown in Fig. 2(a, b). More intense winds of the order 6m/s–7 m/s and 8m/s–9 m/s at 10 m and 80 m respectively exist along the coastlines of Gujarat, Maharashtra, Tamil Nadu, Andhra Pradesh and southern Andaman islands. The most powerful set of wind speeds are encountered along the Gulf of Mannar to Kanyakumari region of the order 7m/s–9 m/s and 9m/s–11 m/s at 10 m and 80 m respectively. The WPD ranges between $100\mathrm{W/m^2}$ to $600\mathrm{W/m^2}$ and $500\mathrm{W/m^2}$ to $1500\mathrm{W/m^2}$ at 10 m and 80 m respectively with highest WPD $\geq$ 1250 $\mathrm{W/m^2}$ along the southern Indian coastline region. This region has the highest wind potential when compared to other regions of research in the Indian coastlines. However, due to the EEZ Restrictions ($\leq$ 20 nm) and the existence of deeper region depths within a few kilometers from the coastline, only some parts of this place of concern is feasible and economical.

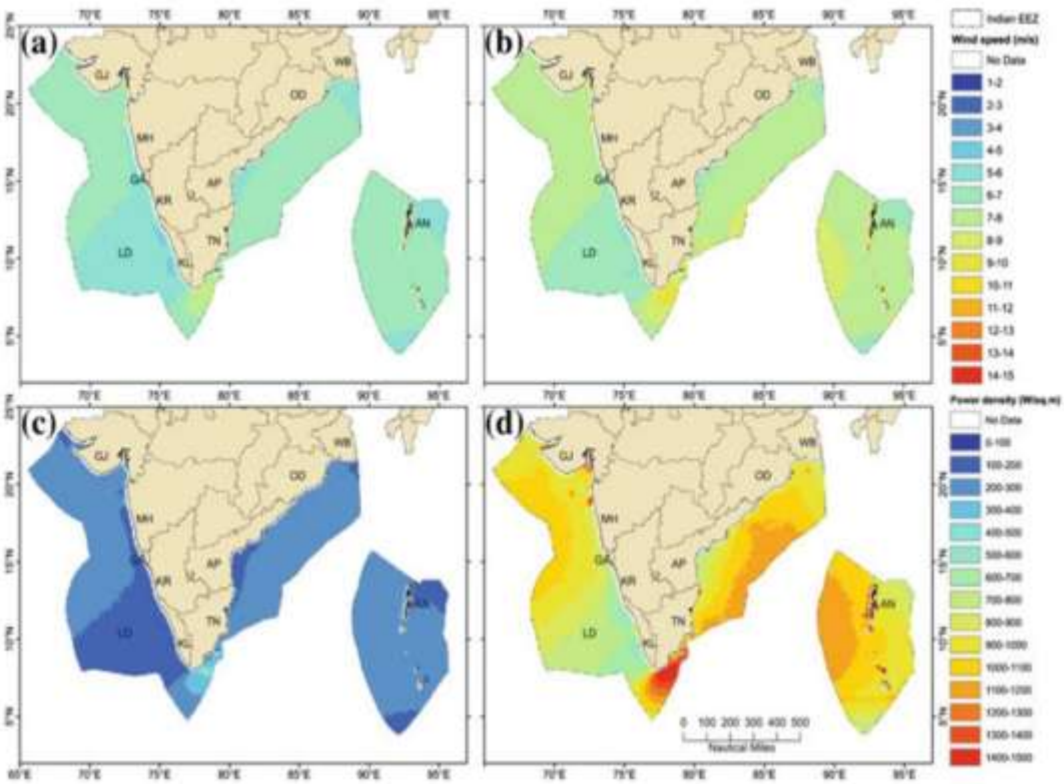

Figure 2 Annual average wind vector speed distribution **(a,b)** annual average wind power density **(c, d)** satisfying within Indian EEZ at 10 m and 80 m altitudes respectively.

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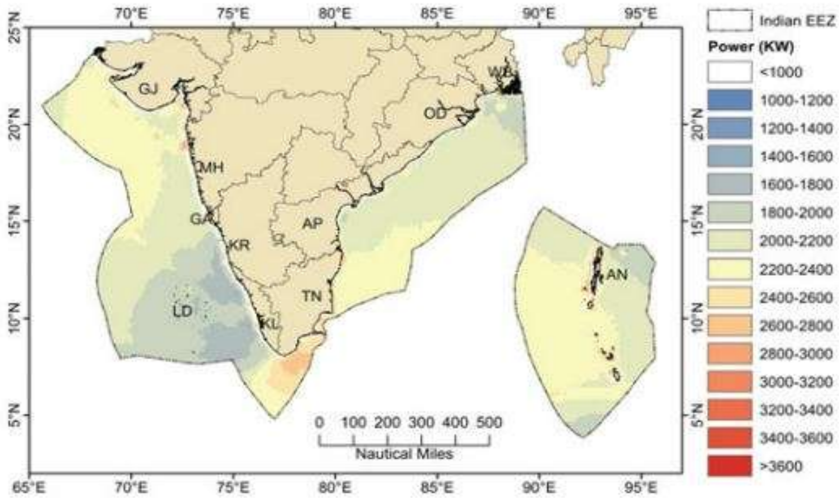
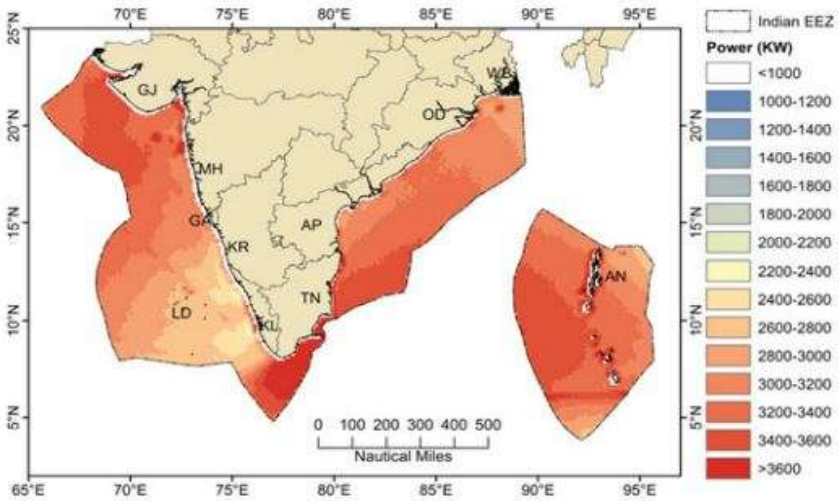
The data given by the major types of turbines i.e. both Vestas V112 3 MW Turbine and Gamesa G128 5 MW Turbine results into a total annual power generation of 3393 TWh and 5182 TWh respectively which is 2.95 and 4.48 times more than the required power (1200 TWh/yr) of the entire country in the financial year 2019 to 2020.



Annual power production (KW) with Vestas V112 3 MW turbine within Indian EEZ



Annual power production (KW) with Gamesa G128 5 MW turbine within Indian EEZ

IV. CONCLUSION

The present study data gives us an idea about the potential of offshore wind power in the Indian EEZ which includes Lakshadweep, Andaman and Nicobar Islands and obviously the mainland based on the collaborative use of QuikSCAT, OSCAT, and ASCAT scatterometers. We thus observed that the Gulf of Mannar to Kanyakumari Coastline possesses the maximum annual average wind speed and WPD. The coastline along Karnataka, Kerala and Goa coasts possesses the least annual average wind speed and WPD. By using Vestas 3M (GM 5M) turbine, the EPG is around 3,380 TWh/yr (5,100 TWh/yr) without including any shipping lanes and visually excluding from the coast almost 50% of total area. The power generated can fulfil 2.9 times to almost 4.5 times of India's anticipated electricity demand of 1200 TWh/yr for the year 2019–2020.

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