INDO-FRENCH TECHNOLOGY MEET

Round Table

MARINE TECHNOLOGIES

Date : 24th October 2013 **Place : New Delhi**

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Outline

- Marine Renewable Energies
- Global scenario
- Wind Energy in India
- Wind Energy Technology
- Offshore Environment
- Offshore Wind turbine Concepts
- Construction and commissioning
- Cost Comparison
- Design Codes
- Recent Research in IIT Madras
- Future Research Thrust Areas

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MARINE RENEWABLE ENERGY

Marine Renewable energy includes

- TIDAL ENERGY
- WAVE ENERGY
- OCEAN THERMAL ENERGY
- OFFSHORE WIND ENERGY

Offshore Wind Energy Technology is similar to Onshore wind energy extraction except that the foundations and structures are located in the water.

Further, the connectivity to the offshore wind mill both in terms of accessibility and power grid connectivity becomes an issue.

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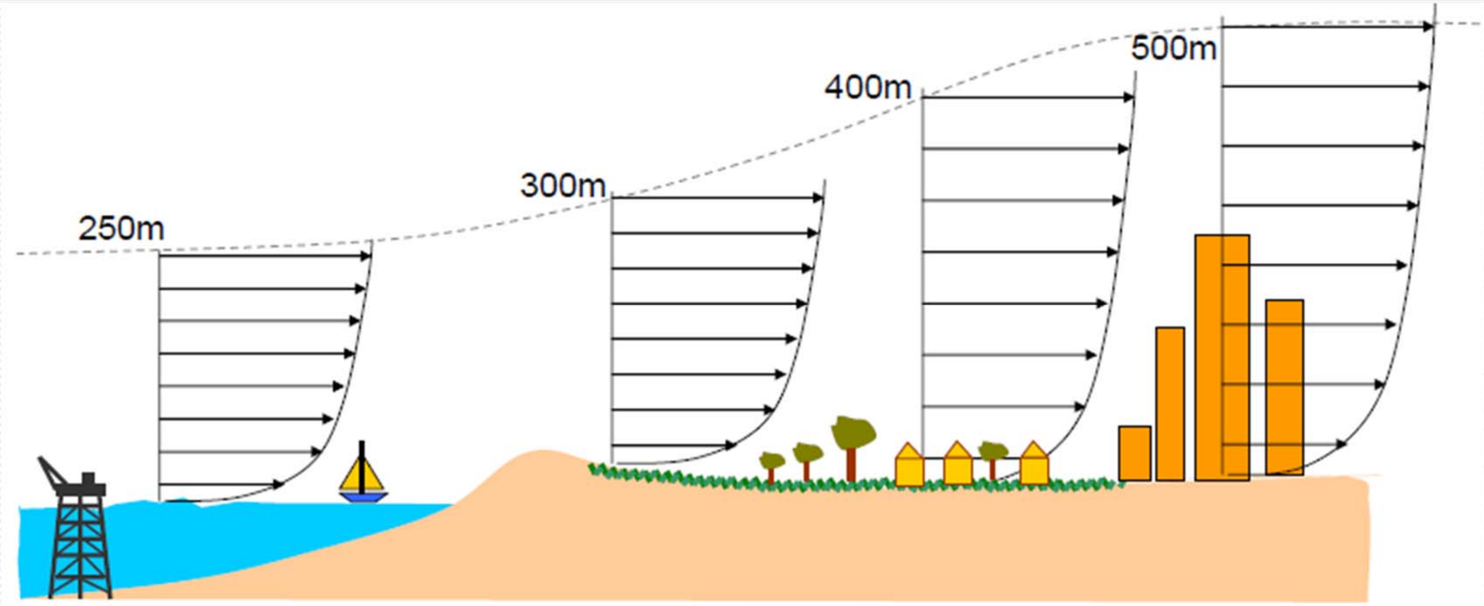
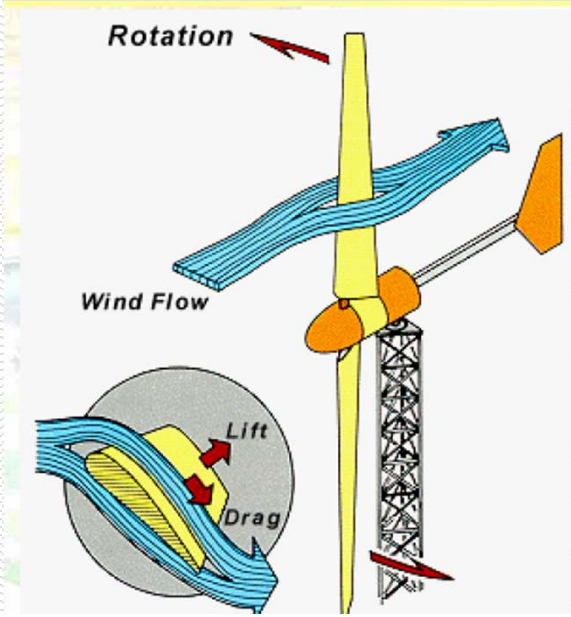
Offshore Wind Energy – Opportunities





- Un-obstructed wind (normally reduced due to terrain factor on land)
- Noise pollution if located within populated area in the order of 100 dB. Hence locating them offshore eliminates the noise pollution.
- Abundant space – No constraint on numbers and location

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ADVANTAGE OF OFFSHORE WIND ENERGY OVER ONSHORE

- Offshore wind velocities are higher and steadier in deeper waters.
- Wind power is directly proportional to cube of wind velocity
- Wind velocity in offshore is more than 20 m/sec and can reach as much as 50 m/sec, whereas in onshore is limited (11 to 15 m/sec).
- Availability of free area for the installation of wind farms.
- Continuous availability of wind in offshore, and the extraction of energy is more efficient.

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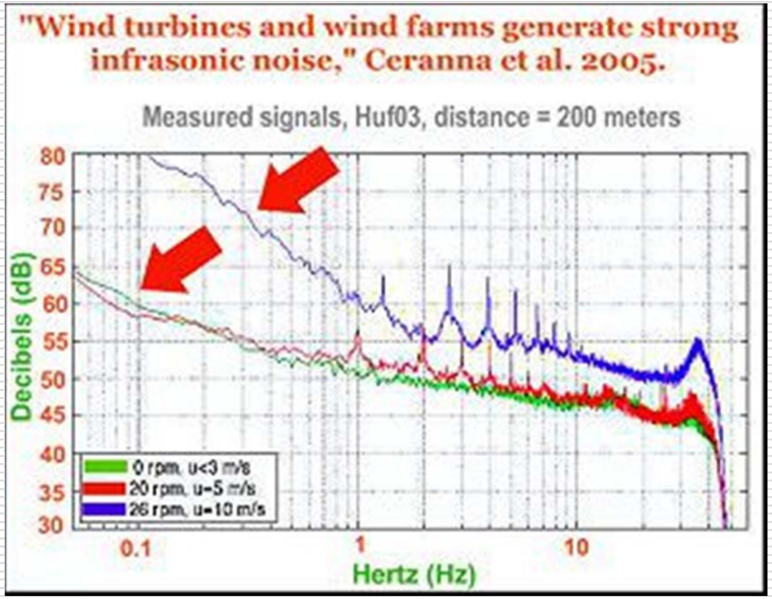
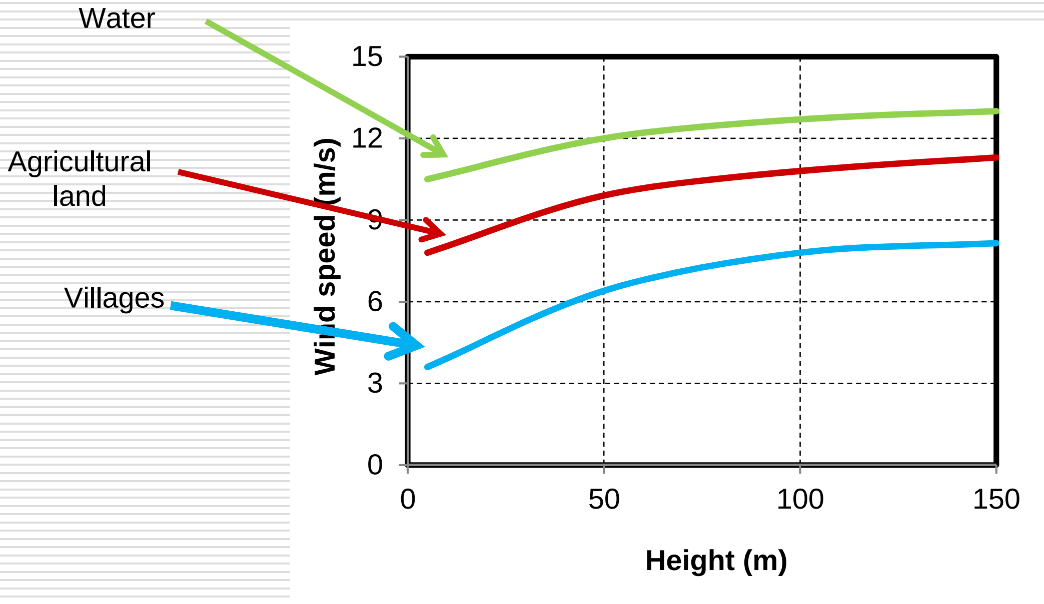
Reasons to move wind farms - offshore

Noise



Roughness-Wind Shear



Wind climate onshore vs. offshore

	Onshore	Offshore
Diurnal pattern	daily maximum	uniform
Seasonal pattern	less pronounced	more pronounced
Stability	diurnal pattern	seasonal pattern
Wind Profile	unstable on average	neutral on average
Mean wind speed	less in land	higher than on land

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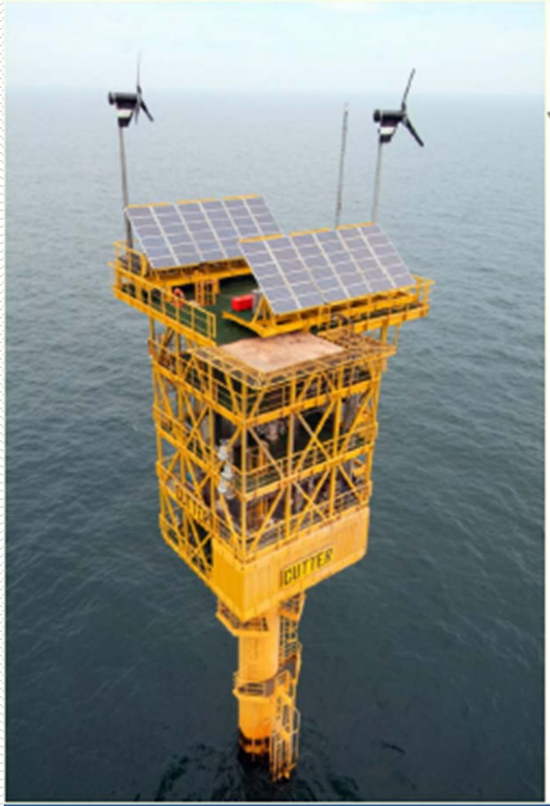
OIL AND GAS APPLICATIONS

UK



Norway

Australia

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OFFSHORE WIND ENERGY

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Onshore Wind Energy Technology

Offshore Oil and Gas Exploration Technology

Offshore Wind Energy Technology

Source: www.offshorewind.org

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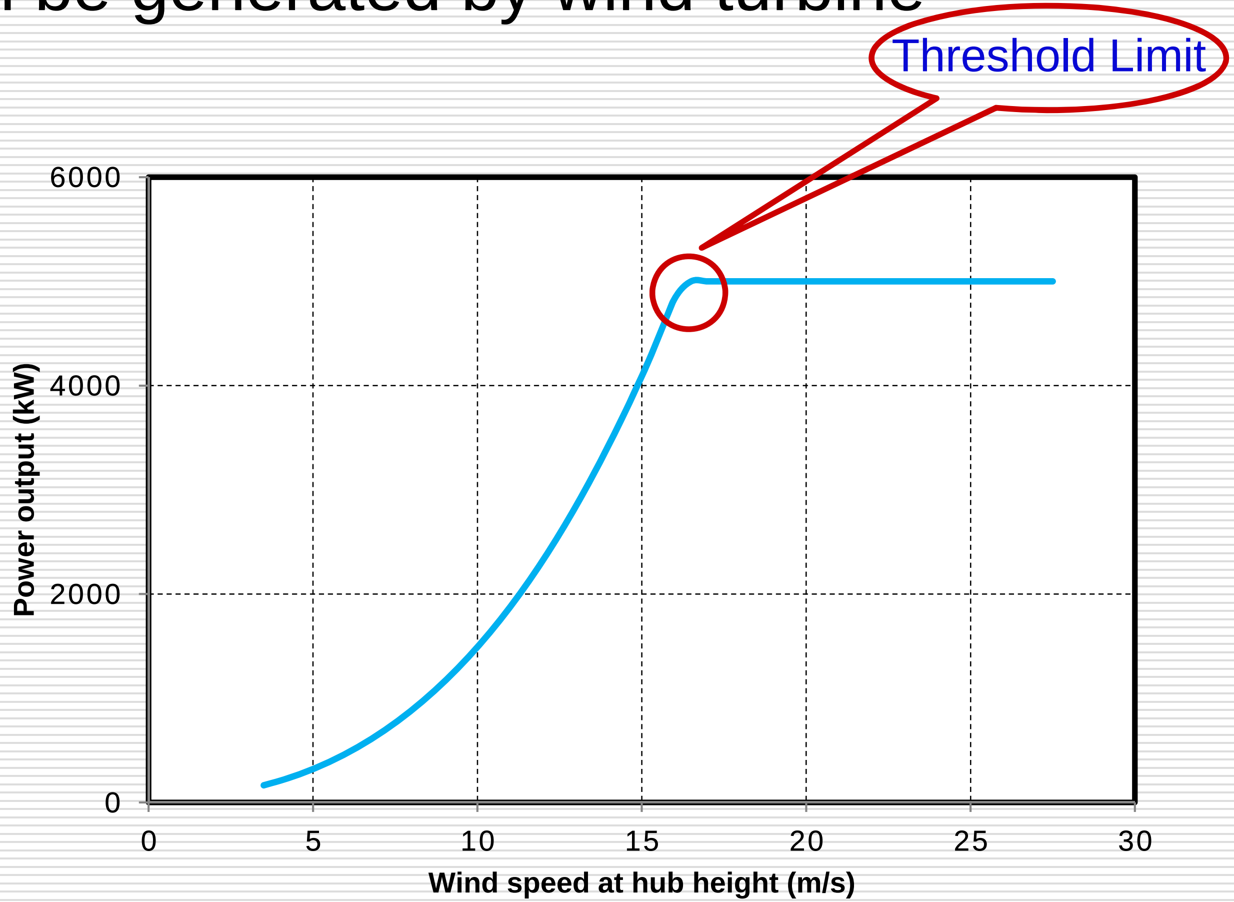
WIND ENERGY TECHNOLOGY

The amount of power that can be generated by wind turbine is given by

$$P = {}^{1}\!/_{2}\,\rho\left(\pi R^{2}\right)V^{3}$$

Where,
P= Power output in kW
R= Radius of the rotor in m
V= wind speed in m/s



Threshold limit: Beyond which, even if the wind speed increases, power output is constant

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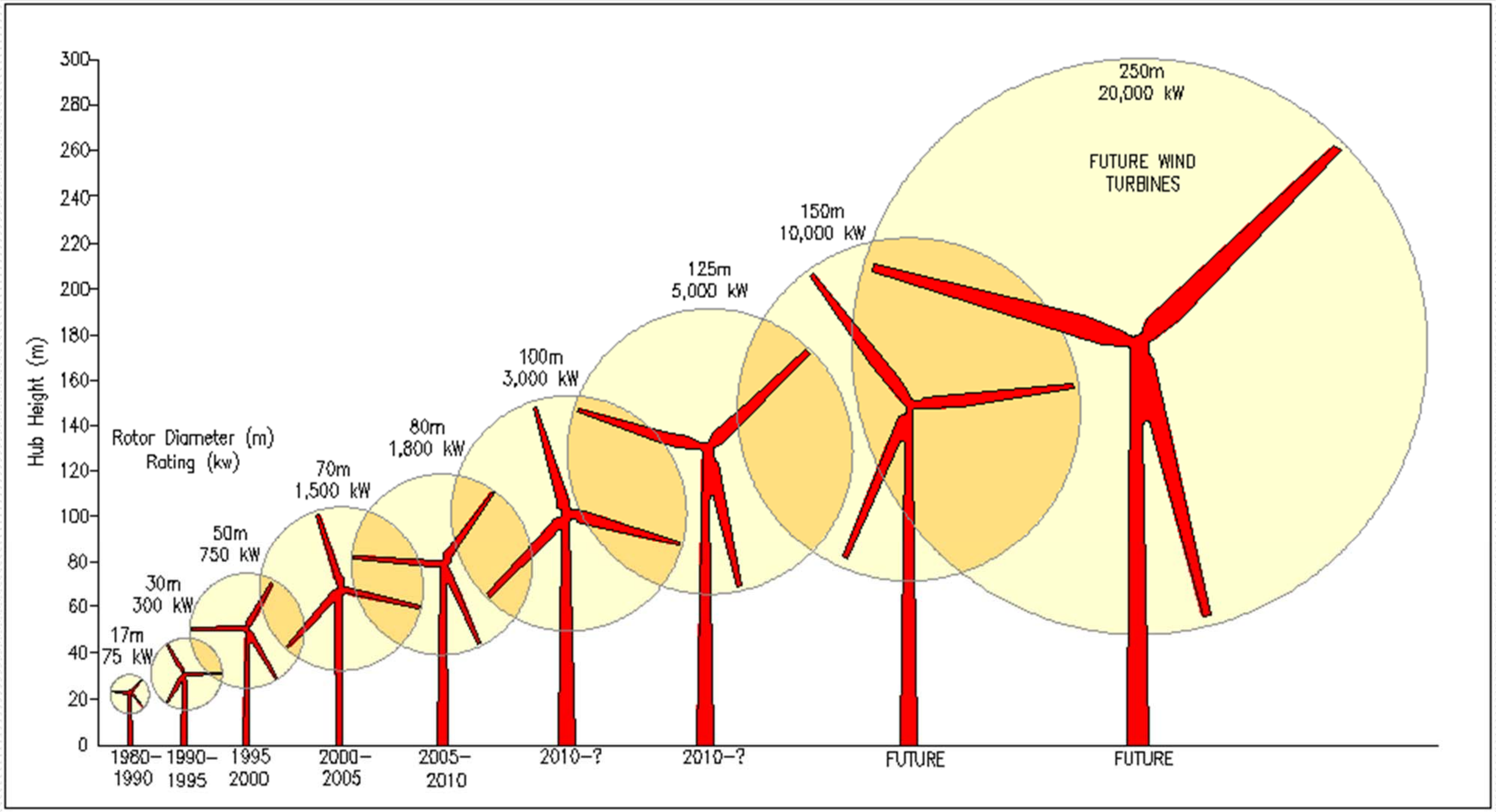
Progress in size of the wind turbine in future



Progressive increase in size of the wind turbines are aimed at economically and effectively harnessing the offshore wind energy

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GLOBAL SCENARIO

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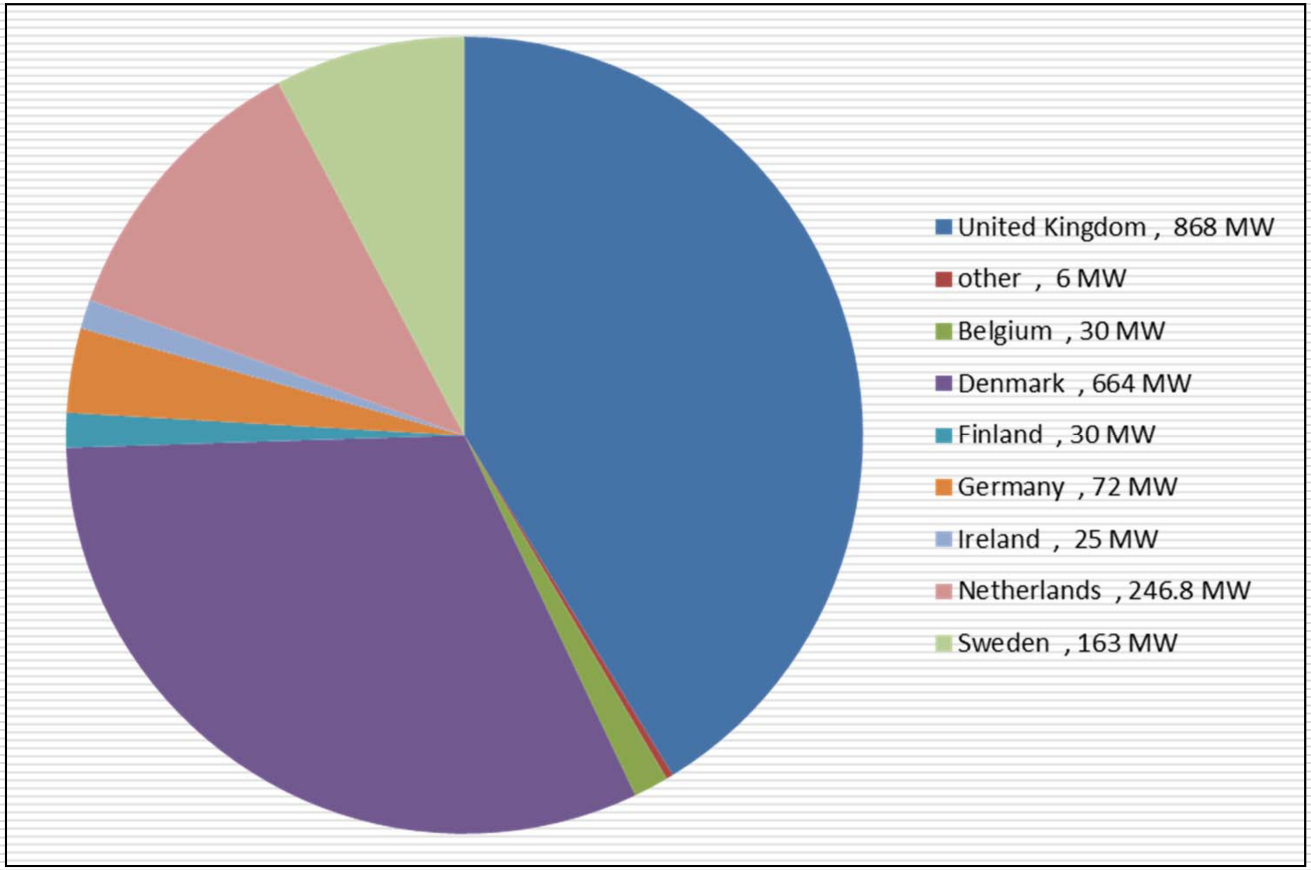
Installed offshore wind capacity by country

- United Kingdom leads in total installed capacity, followed by Denmark and Netherlands.
- At present, several other countries including **INDIA** have begun looking toward offshore wind to meet their energy needs.



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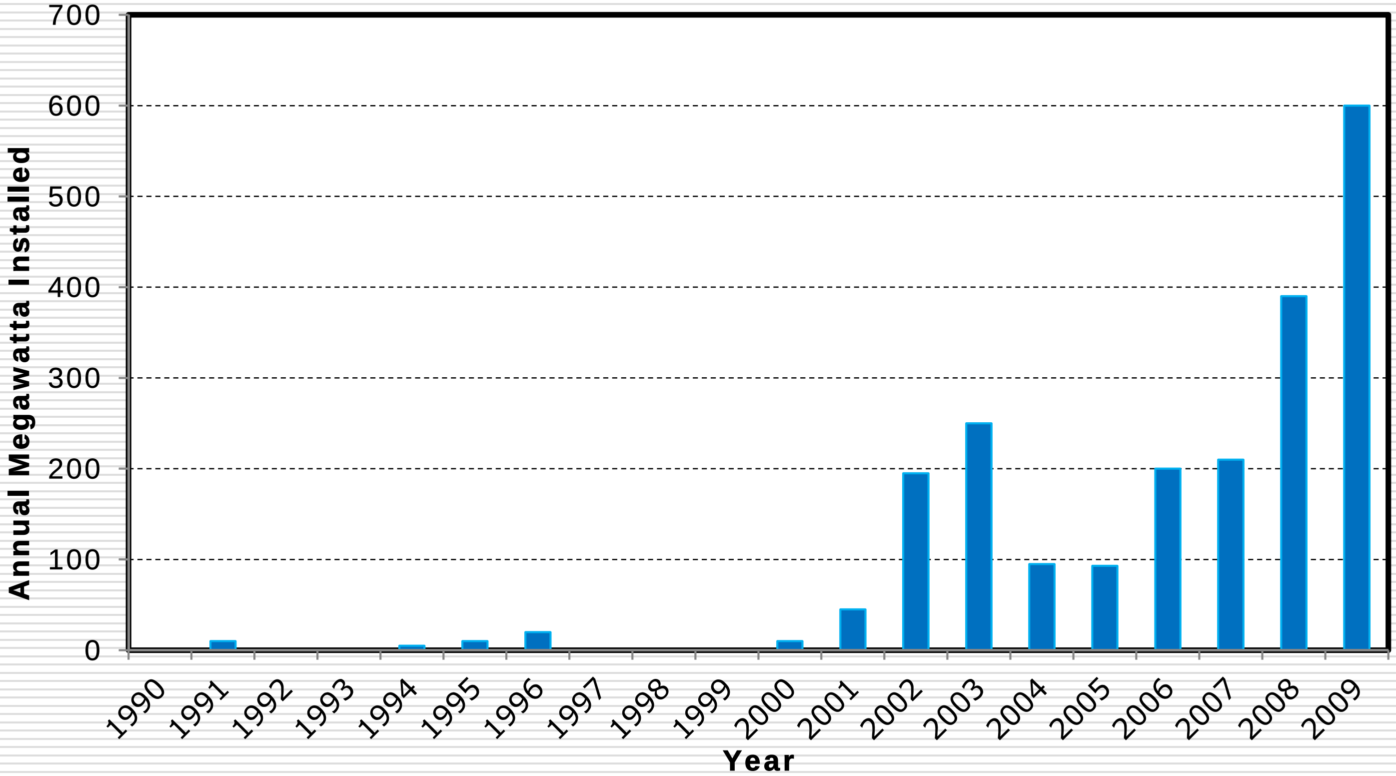
Installed offshore wind energy capacity worldwide by year

- World wide offshore wind energy market shows a more sustained growth in the annual installation.
- European Union has set goal of 150GW of offshore wind capacity by 2030.



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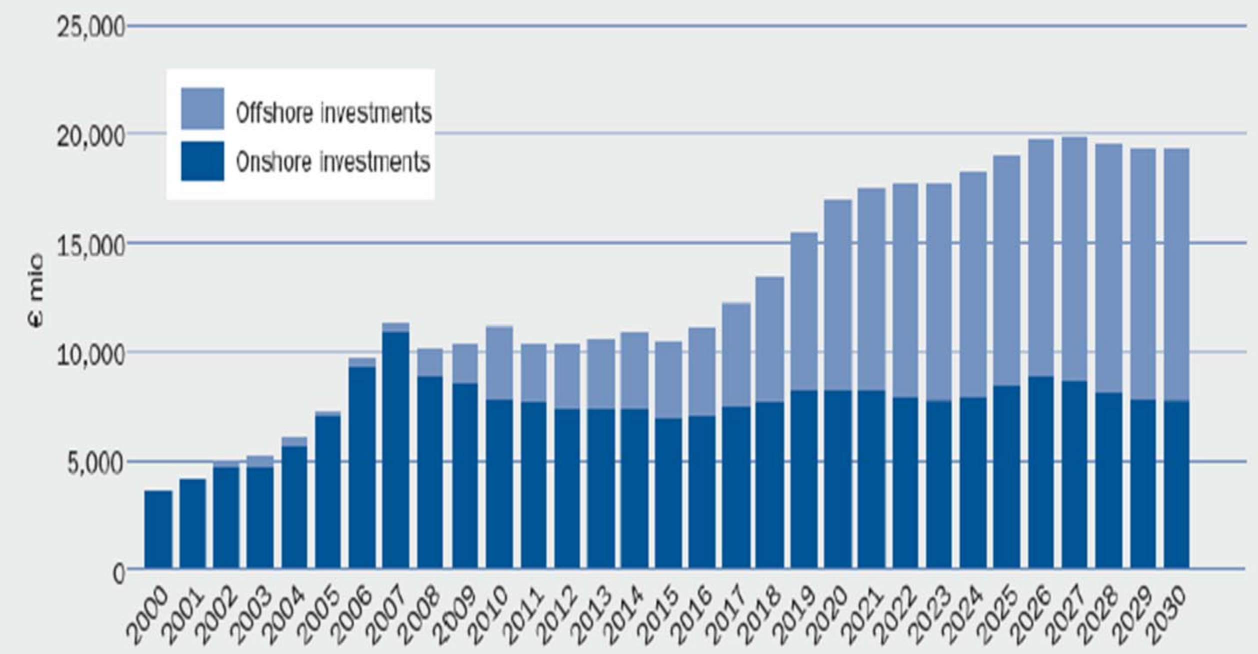
Global wind energy investments - Past, Present and Projected

- The investments in offshore wind energy drastically increases from the year 2015.
- This clearly indicates the necessity and importance of Offshore wind energy.



Source: EWEA

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WIND ENERGY IN INDIA

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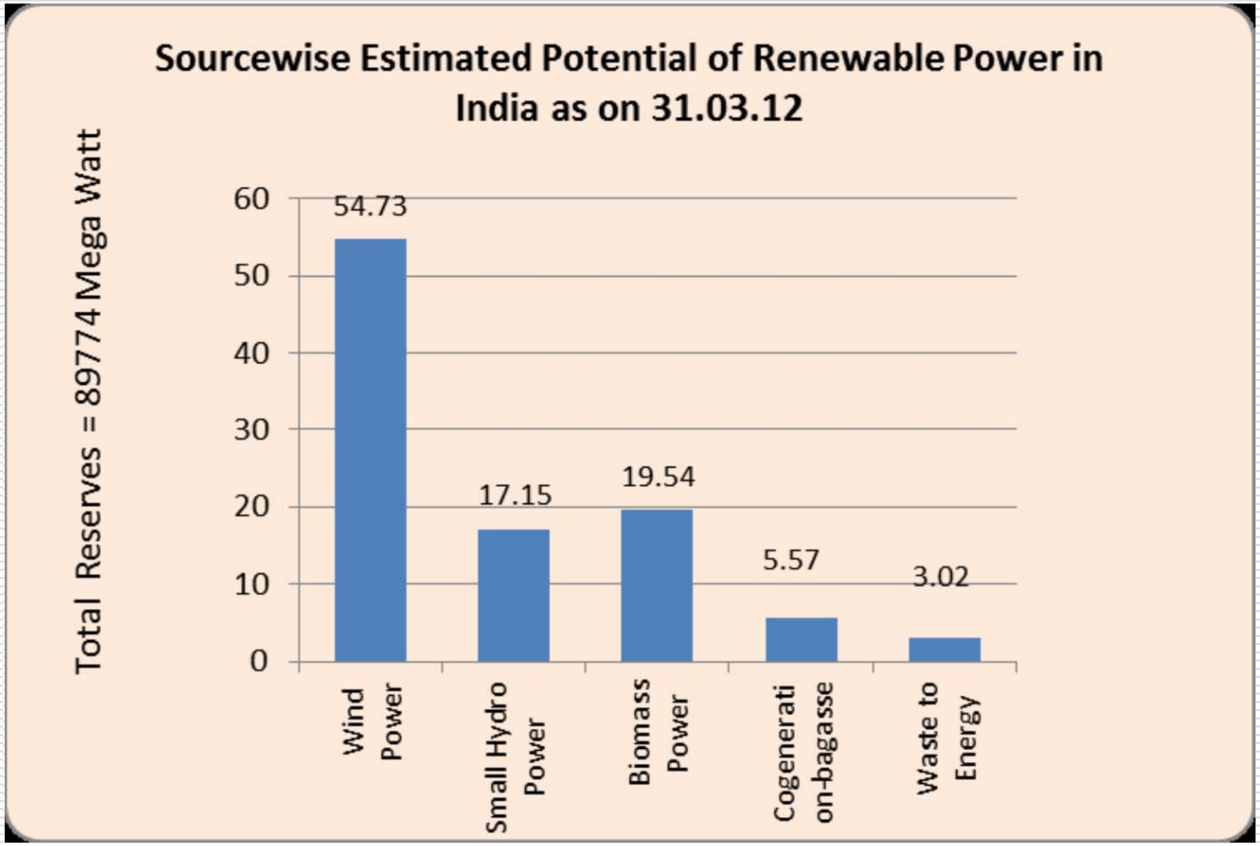
Potential of different renewable power in India



(Source: Energy statistics 2013 by Government of India)

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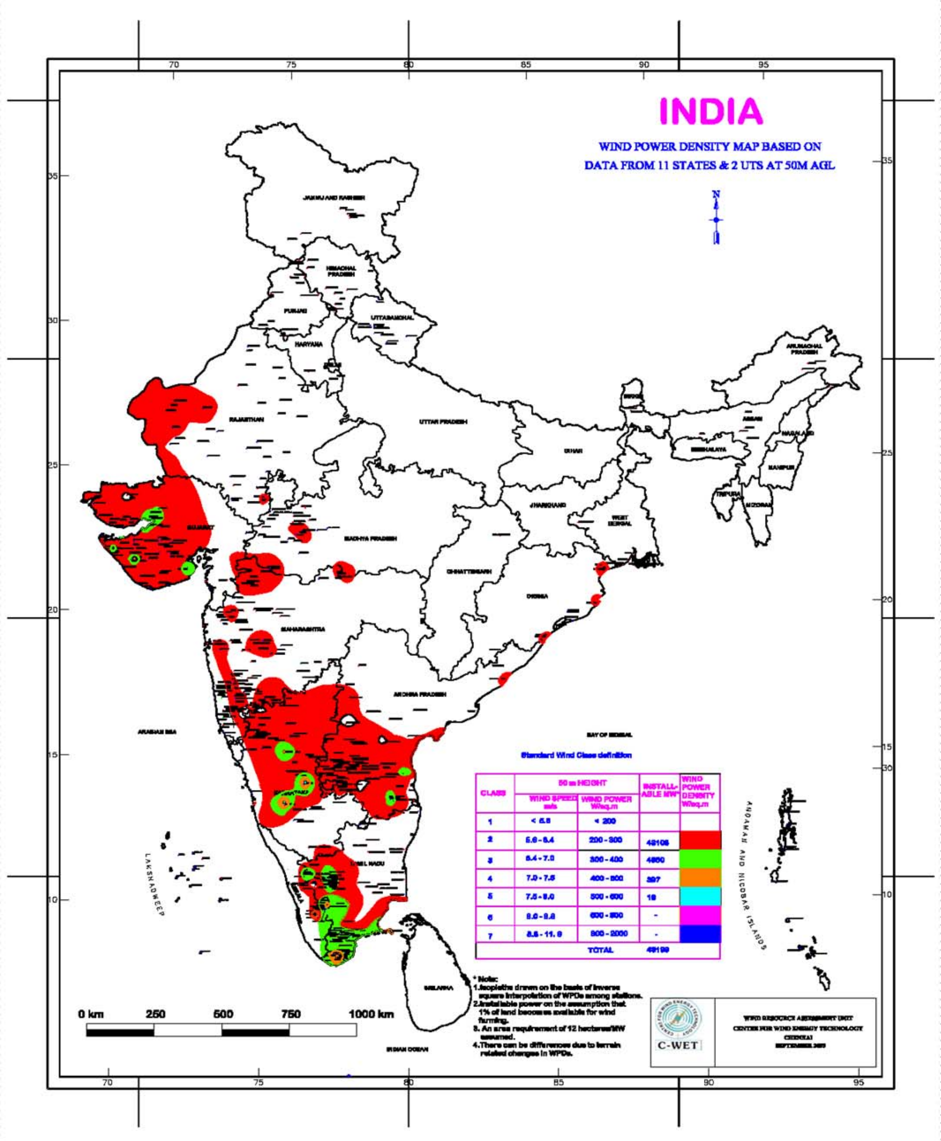
ONSHORE WIND ENERGY MAP

Standard Wind Class Definition

	50 m HEIGHT			
CLASS	WIND SPEED	WIND POWER	INSTALLABLE	WIND POWER DENSITY
	KNOTS	W/sq.m	MW	W/sq.M
1	< 6.0	< 200		
2	6.0-6.4	200-300	43104	
3	6.4-7.0	300-400	4050	
4	7.0-7.5	400-500	207	
5	7.5-8.0	500-600	10	
6	8.0-8.8	600-800		
7	8.8-11.0	800-2000		
		Total	47371	



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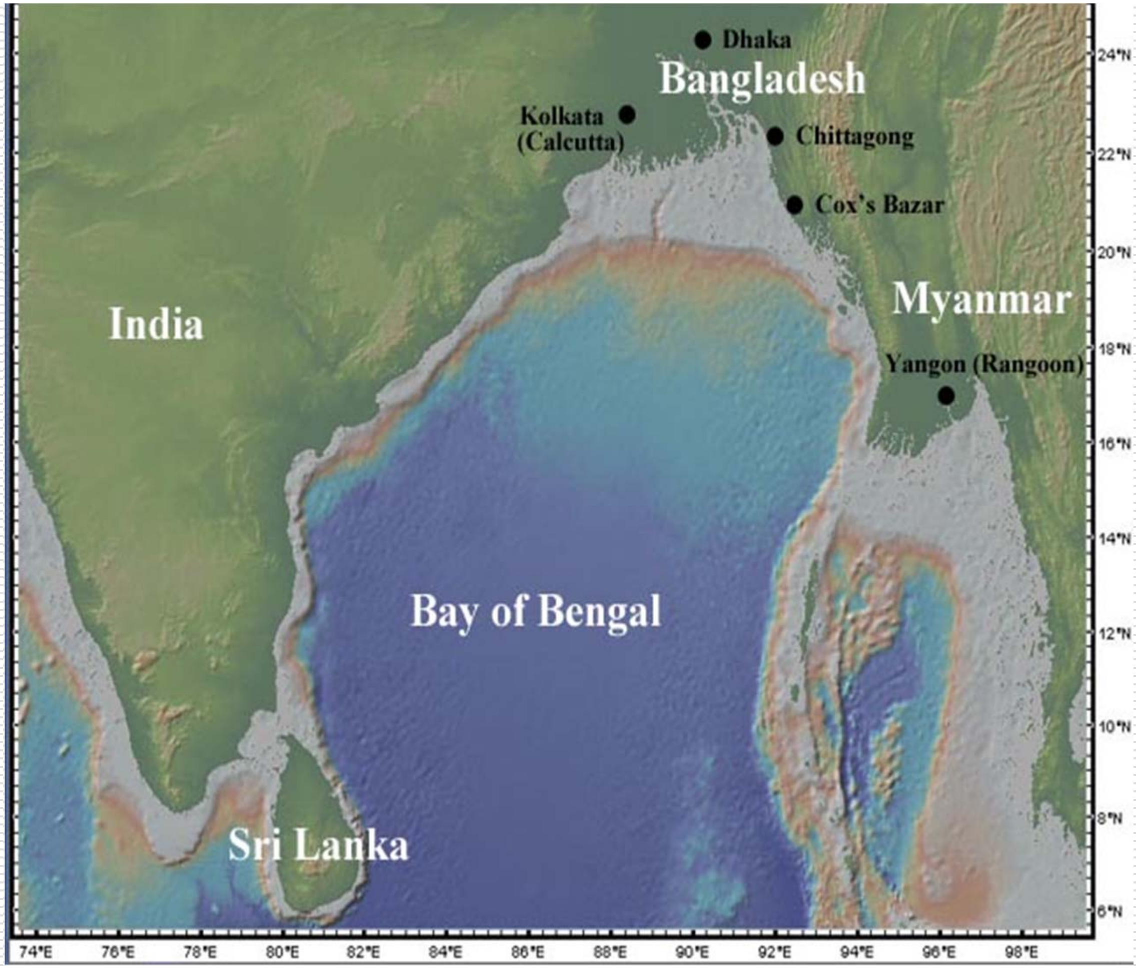
Bathymetry of the Indian coast.

- The shallow waters of the Continental Shelf (mostly shallower than 200 meters) are shaded whitish-grey.
- Along the east coast, the water depth near the coast is less than 200 m.
- From Kolkata, India to Cox's Bazar, Bangladesh, the ocean bottom is shallow and allows storm surges to pile up to great depths.
- Fifteen of the twenty deadliest tropical cyclones in world history have been Bay of Bengal storms that have hit Bangladesh, India, or Myanmar, bringing catastrophic storm surges.



Source: geomapapp.org.

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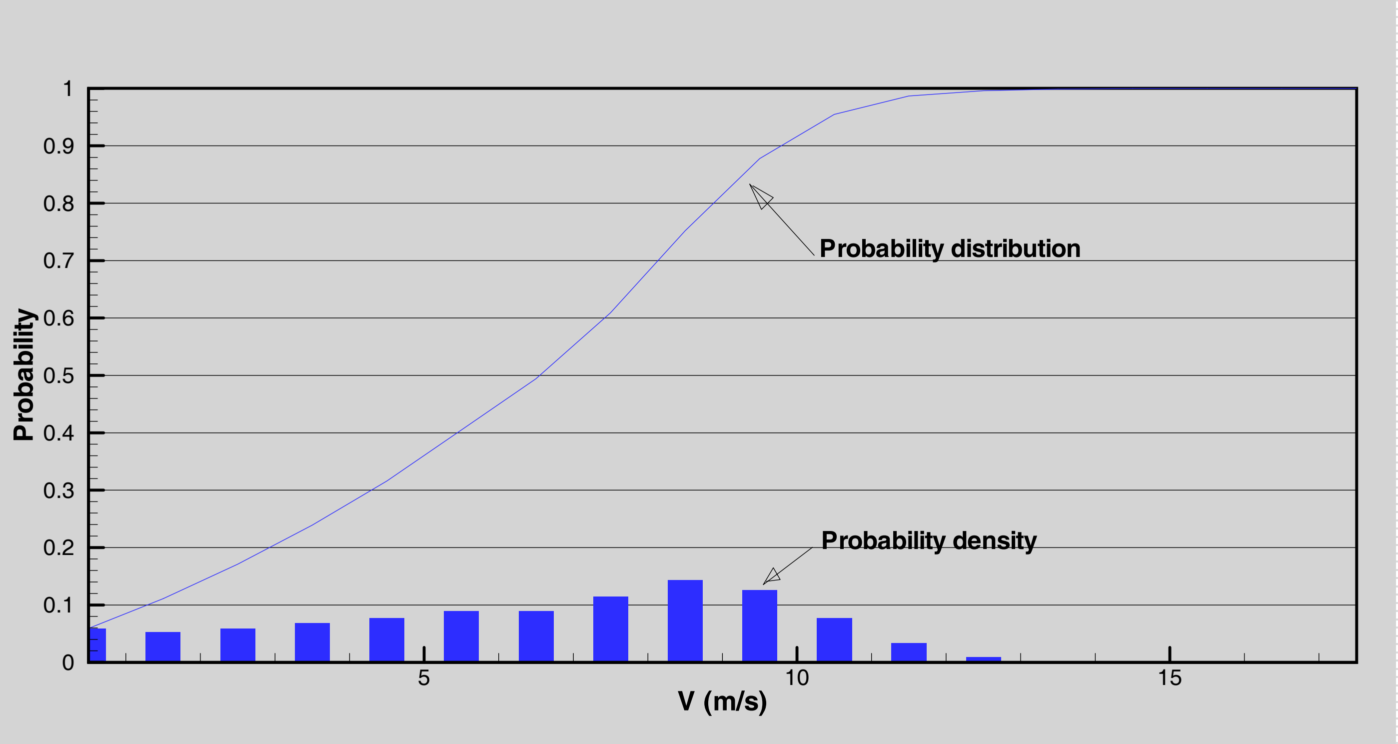
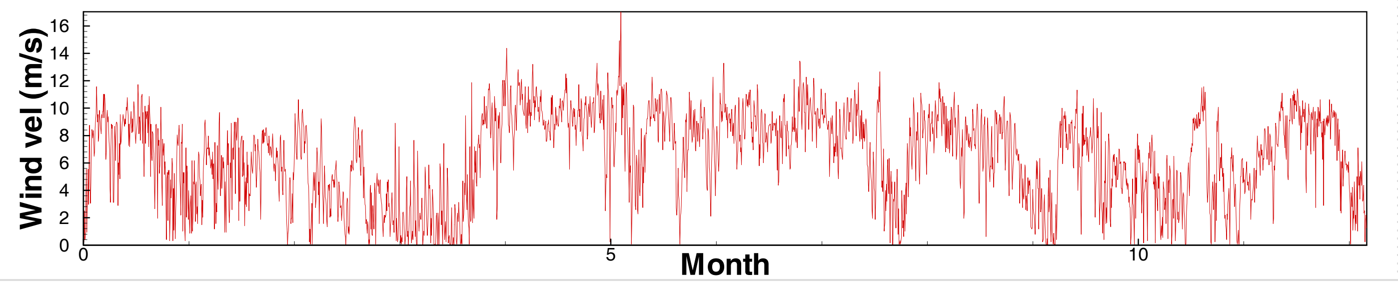
Wind Statistics

Typical measured wind record together with the probability distribution is shown in the figure for east coast.

The statistics indicate considerable variation but the mean value is around 10 m/sec.

Note that the measured record does not include cyclonic data.





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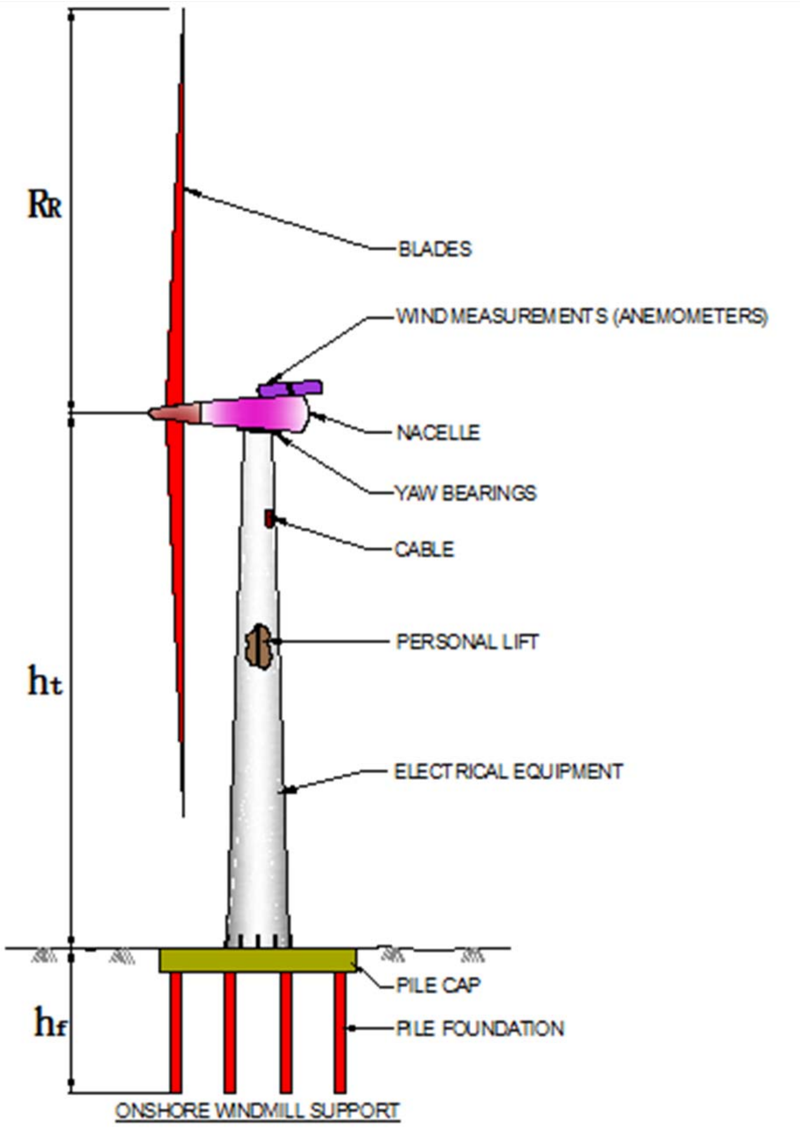
ONSHORE WIND ENERGY

- The Indian wind energy sector has an installed capacity of 17,365 MW (as on March 31, 2012). In terms of wind power installed capacity, India is ranked 5th in the World.
- Indian Wind Energy Association has estimated that the 'on-shore' potential for utilization of wind energy for electricity generation is of the order of 102 GW.
- The unexploited resource availability has the potential to sustain the growth of wind energy sector in India in the years to come.



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OFFSHORE ENIRONMENT

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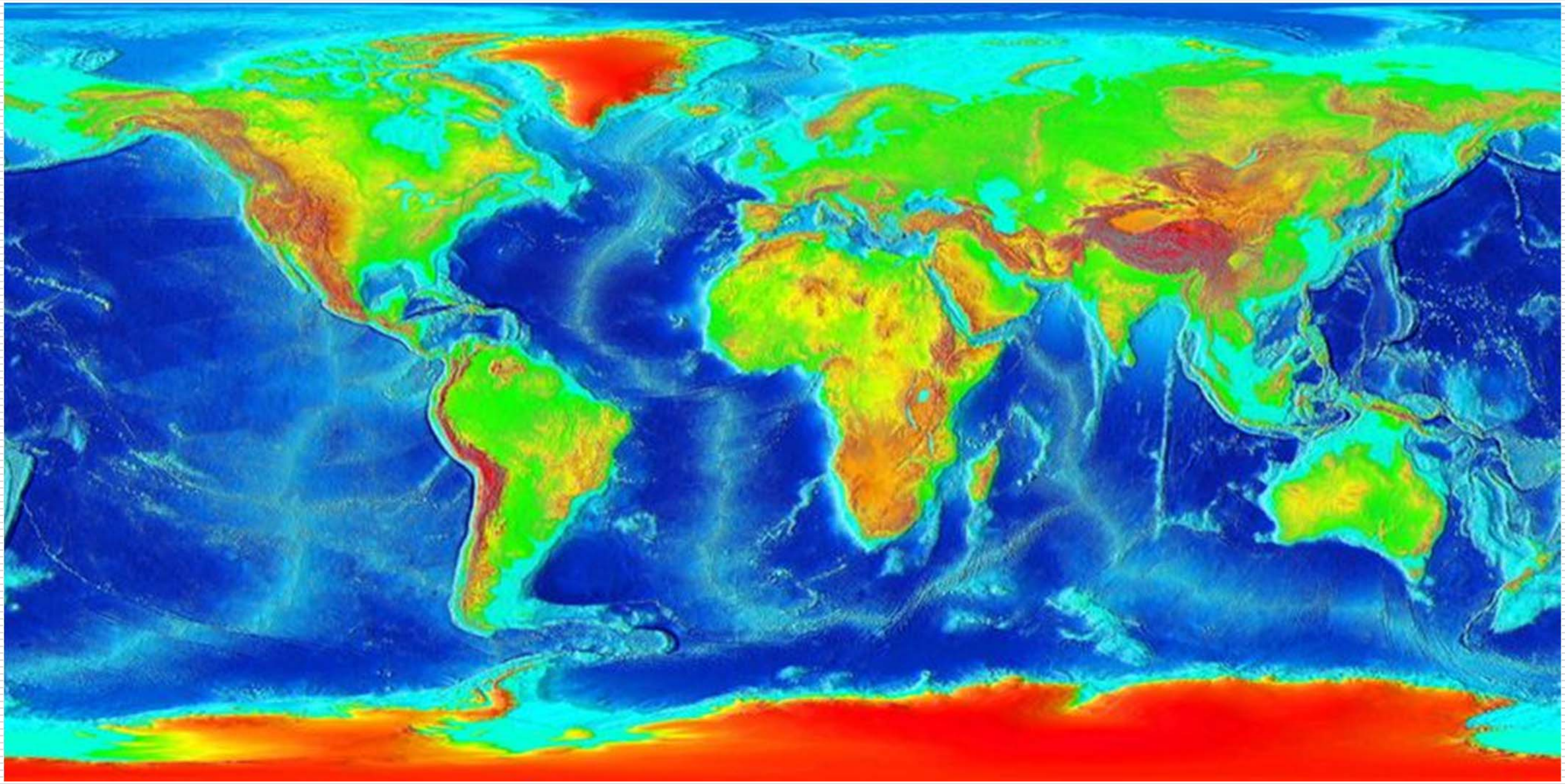
CONTINENTAL SHELF



Continental Shelf

Source : Wikipedia.org

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OFFSHORE ENVIRONMENT AND CHALLENGES

- Sea waves can reach as much as 20m in deep water condition (depth > 50m)
- Wind velocity can reach as much as 200 kM/hour during cyclone
- Sea water is corrosive and hence the steel structures and wind turbine may be subjected to corrosion.
- Storm surge and tidal changes may require the wind turbine tower and blades (bottom tip) to be sufficiently elevated.
- The distance from shore and its connectivity to the **power grid and accessibility for repair** and maintenance of the turbine and control system becomes an issue and may be costlier.

In all, the prevailing conditions are difficult than the onshore and need to find suitable solution for each.

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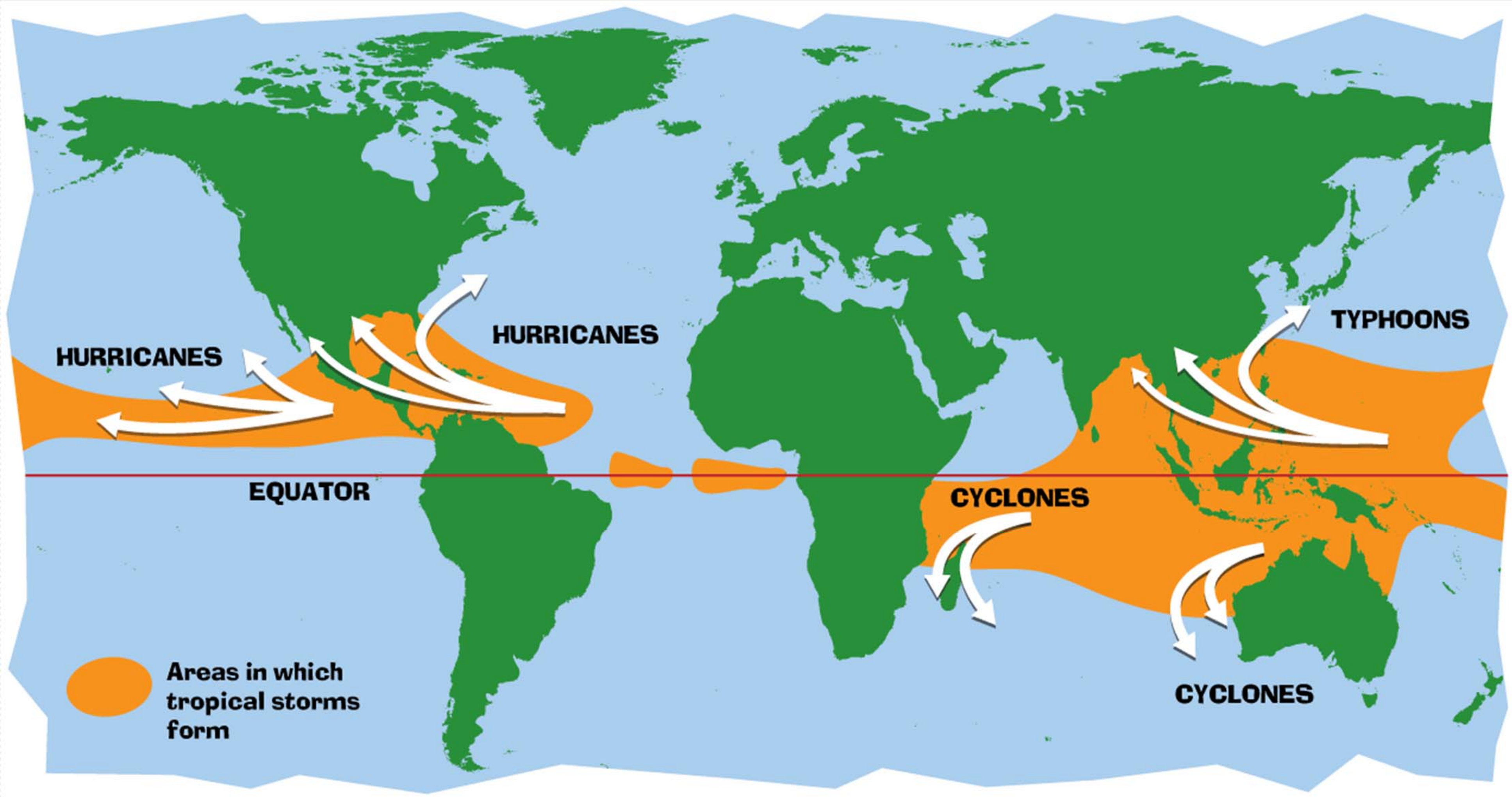
Areas in which tropical storms form



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CYCLONES AND STORMS

Cyclonic storms are very common in the east coast.

Table shows the crossing of cyclones in the southern east coast including the recent one crossed in Orissa.

The storm surge in many of the cyclones exceed 3m and the wind speed has crossed 200 km/hour in many occasions.

It can be observed from the above table that the vulnerability of wind farms to cyclonic storms is high.

Legend

D : Depression
CS : Cyclonic storm
SCS : Severe Cyclonic Storm

S.No	Year	Month	Place of Crossing	Max Intensity
1	1960	Nov.	Near Chennai	CS
2	1962	May	Near Cuddalore	CS
3	1963	Oct.	Bet. Pondicherry and Cuddalore	SCS
4	1964	Nov.	South of Chennai	SCS
5	1966	Apr.-may	Near Cuddalore	SCS
6	1966	Nov	South of Chennai	SCS
7	1966	Nov	South of Chennai	SCS
8	1967	Dec.	Near Nagapattinam	SCS
9	1969	Oct.	South of Chennai	CS
10	1972	Dec.	North of Cuddalore	SCS
11	1977	Nov.	South of Nagapattinam	SCS
12	1984	Nov/Dec.	North Karaikal	SCS
13	1991	Nov.	Near Karaikal	CS
14	1993	Dec.	Near Karaikal	SCS
15	1994	Oct	Over Chennai	SCS
16	1996	Nov/Dec	Near Chennai	SCS
17	2000	November	Bet. Chennai & Nagapattinam	SCS
18	2001	October	Near Chennai	CS
19	2003	December	Near Chennai	SCS
20	2005	October	Near Chennai	D
21	2006	October	Near Chennai	CS
22	2007	October	Bet. Chennai & Nagapattinam	D
23	2008	November	Bet. Chennai & Nagapattinam	CS
24	2009	December	Near Chennai	CS
25	2011	December	Near Cuddalore	CS
26	2012	October	Near Pondicherry	CS
27	2013	October	Near Gopalpur	SCS

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Wind Speed and its effects

Knots	Beaufort	m/s	Km/h	Label	Effect on sea	Effects on land
<1	0	0-0.2	<1	Calm	Sea like a mirror	Calm. Smoke rises vertically.
1-3	1	0.3-1.5	1-5	Light Air	Ripples	Wind motion visible in smoke.
4-6	2	1.6-3.3	6-11	Light Breeze	Small wavelets	Wind felt on exposed skin. Leaves rustle.
7-10	3	3.4-5.4	12-19	Gentle Breeze	Large wavelets. Crests begin to break.	Leaves and smaller twigs in constant motion.
11-15	4	5.5-7.9	20-28	Moderate Breeze	Small waves, becoming larger, fairly frequent white horses	Dust and loose paper raised. Small branches begin to move.
16-21	5	8.0-10.7	29-38	Fresh Breeze	Moderate waves,	Branches of a moderate size move.
22-27	6	10.8-13.8	39-49	Strong breeze	Large waves begin to form;	Large branches in motion.
28-33	7	13.9-17.1	50-61	High wind, near gale	Sea heaps up	Whole trees in motion.
34-40	8	17.2-20.7	62-74	Gale	Moderately high waves of greater length;	Twigs broken from trees. Cars veer on road.
41-47	9	20.8-24.4	75-88	Severe Gale	High waves.	Larger branches break off trees
48-55	10	24.5-28.4	89-102	Storm	Very high waves with long over-hanging crests.	Trees are broken off or uprooted,
56-63	11	28.5-32.6	103-117	Violent Storm	Exceptionally high waves	Widespread vegetation damage.
64-71	12	>32.7	>118	Hurricane	Sea completely white	Considerable and widespread damage to vegetation,

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OFFSHORE WIND TURBINE SUPPORT SYSTEM

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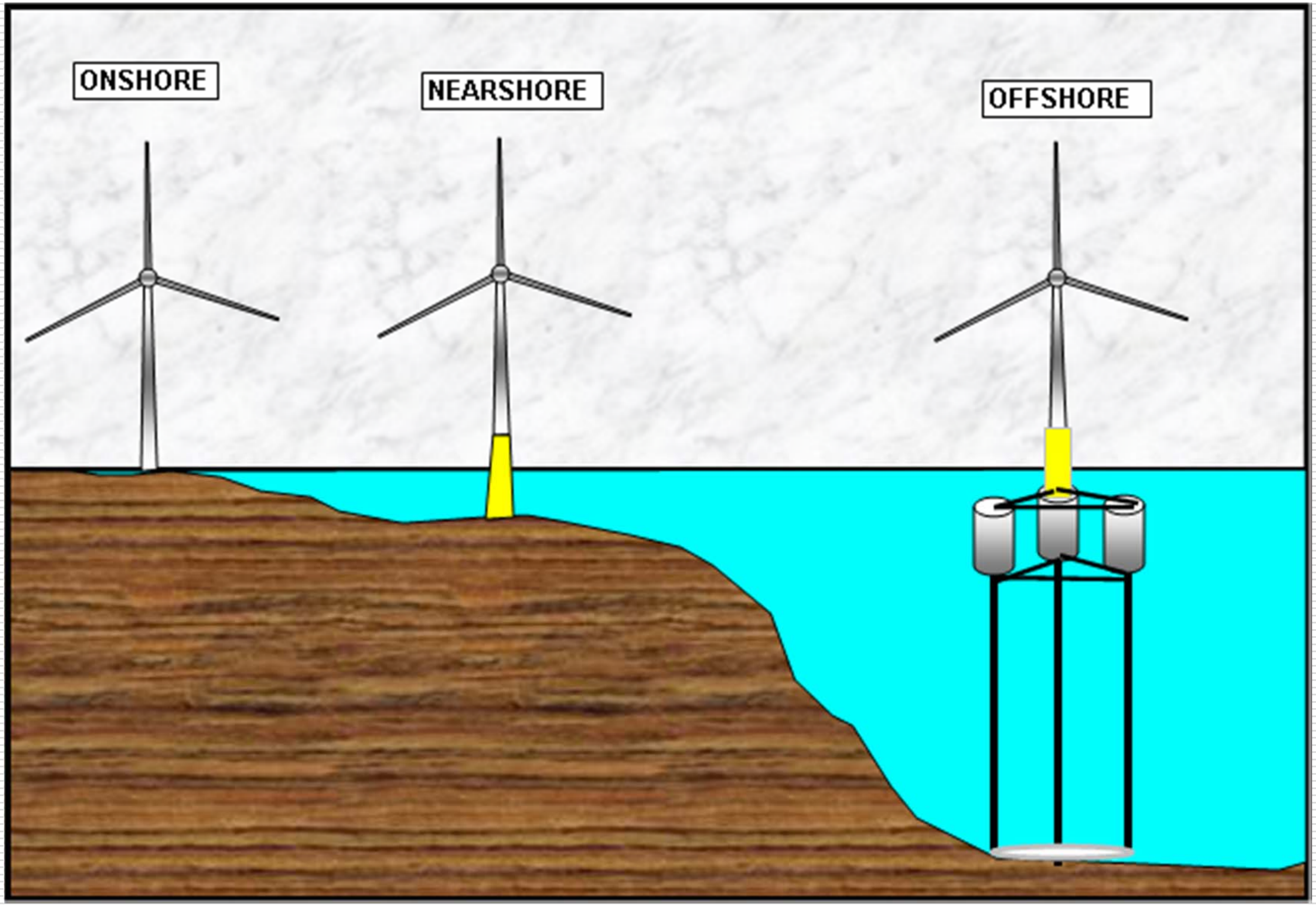
OFFSHORE WIND TURBINE CONCEPTS



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OFFSHORE WIND TURBINE CONCEPTS

OFFSHORE WIND TURBINE SUPPORT STRUCTURES

SHALLOW WATER STRUCTURES
Water depth 0-30 m

- Gravity structures
- Monopiled structures

TRANSITIONAL WATER STRUCTURES
Water depth 30-100 m

- Tripod tower
- Jacket (truss)
- Enhanced suction bucket or gravity base

DEEP WATER STRUCTURES
Water depth >100 m

- Semi-submersible
- Tri-floater
- Barge
- Spar-buoy.

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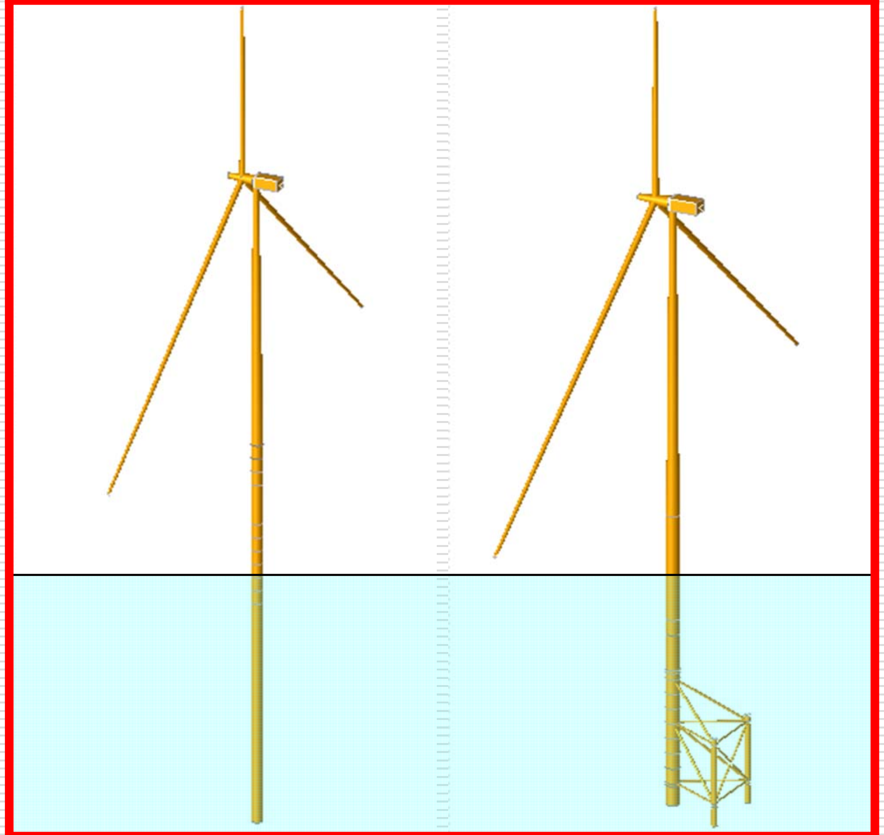
VARIOUS CONCEPTS OF FIXED SUPPORT STRUCTURES

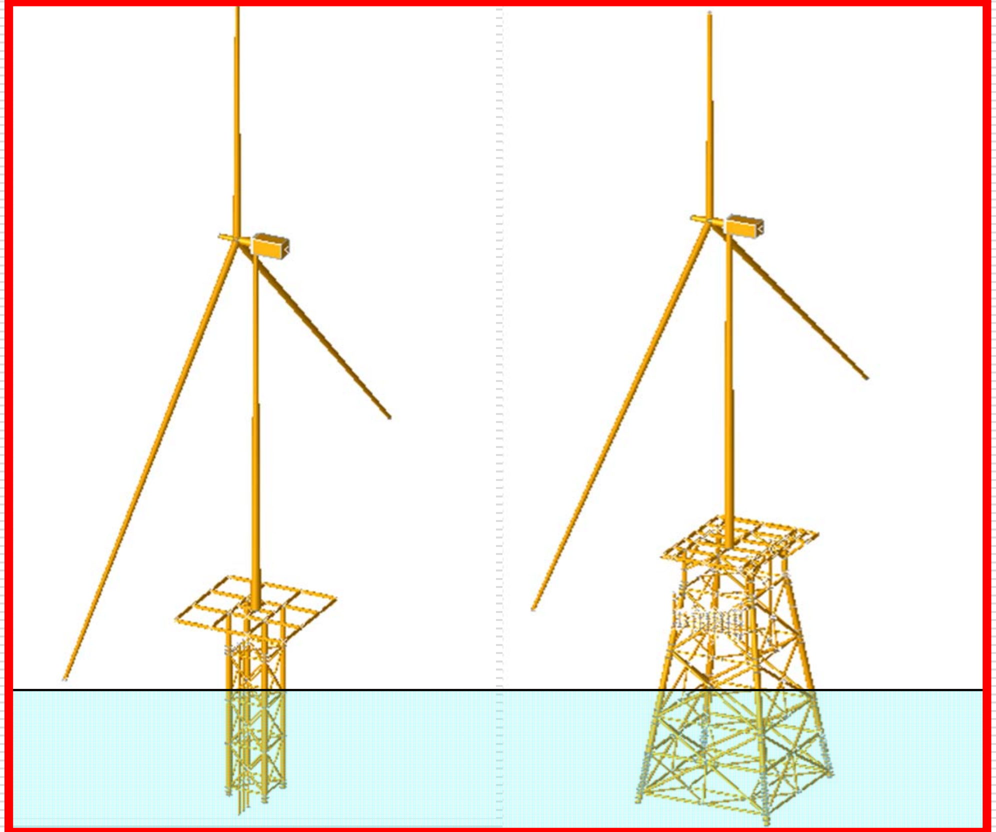
Mono Pile Concepts



Mono Pile without Guy Wire

Braced Mono Pile

Jacket type Concepts



4 Legged Jacket Structure

4 Legged Jacket Structure with Batter Piles

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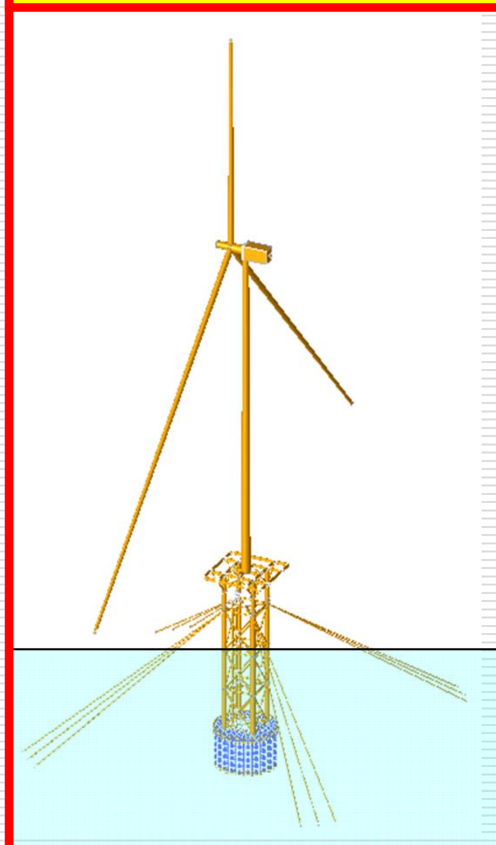
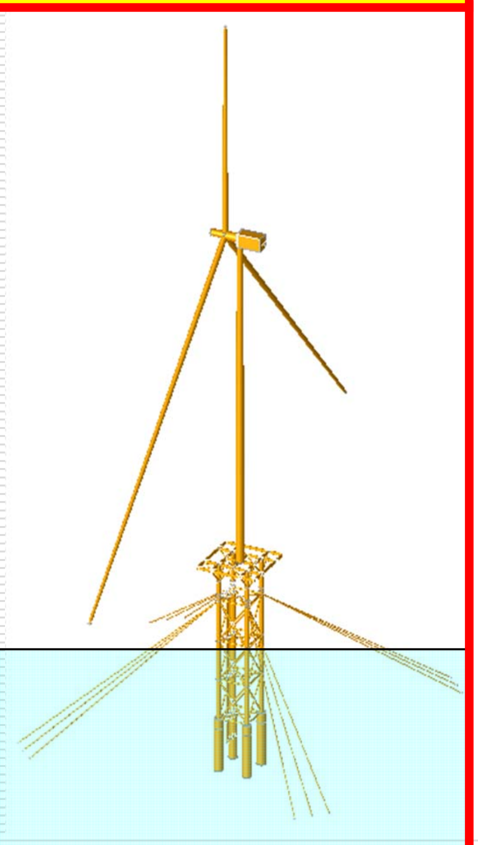
VARIOUS CONCEPTS OF FIXED SUPPORT STRUCTURES

Caisson type Concepts

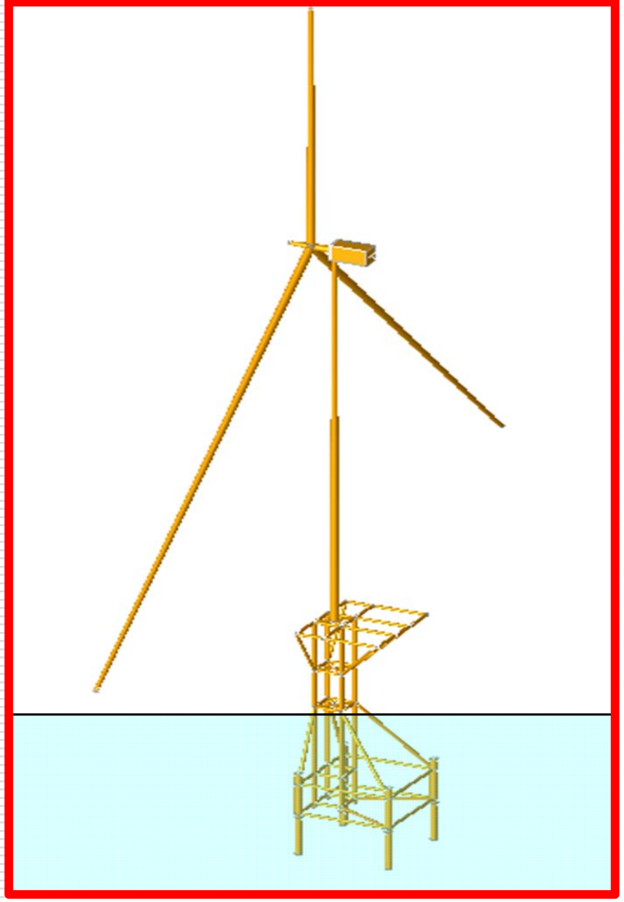


4 Legged Jacket with Hollow Base Steel Caisson



4 Legged Jacket with Steel Caisson with Each Legs

Pile type



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OFFSHORE WIND TURBINE CONCEPTS

❑ Near shore Structures

- ❑ Use of existing Coastal structures such as breakwaters and construct foundation for supporting wind mills
- ❑ Identification of existing coastal structures and deployment of wind mills on to them to produce power without substantial initial cost.
- ❑ Near shore Wind Farms using moored floating barges

❑ Offshore Structures

- ❑ Offshore support foundations based on fixed type concept for shallow water depths
- ❑ Offshore supports foundations based on moored floating structures

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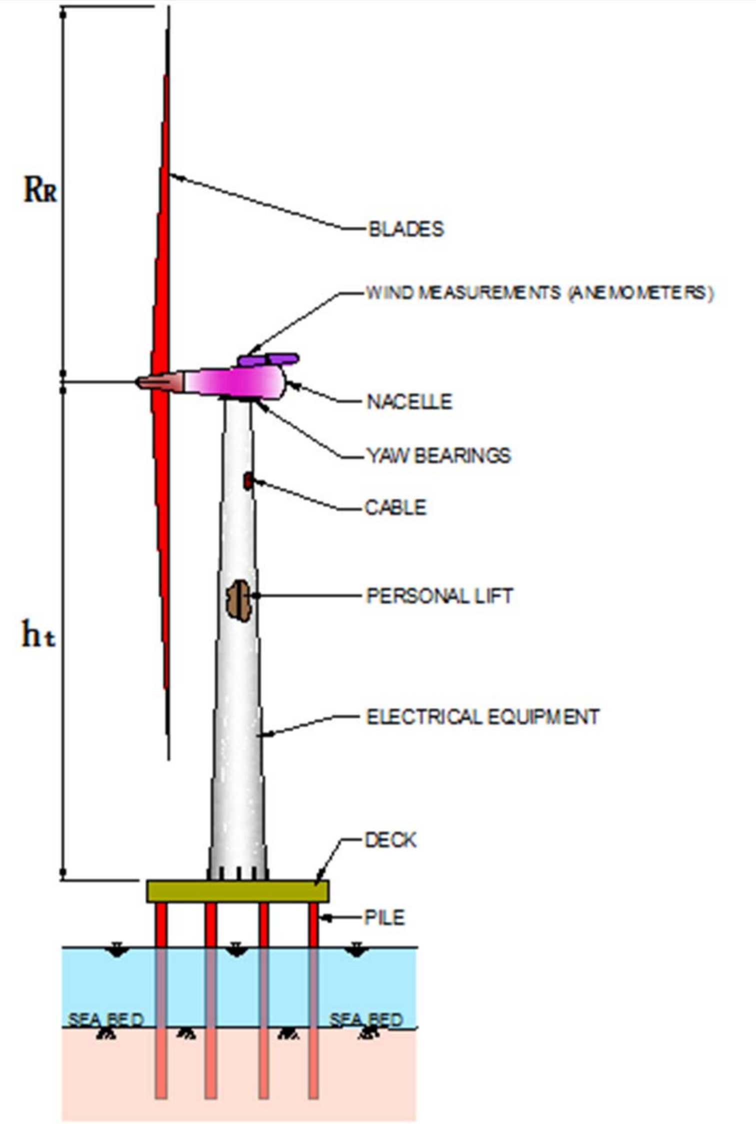
OFFSHORE WIND TURBINES

The support structures for wind turbines near the coasts and offshore are far more complex when compared to onshore structures.

Factors influencing the design of the support structures are

- Soil conditions
- Water depth
- Environment
- Type of wind turbine
- Installation methods



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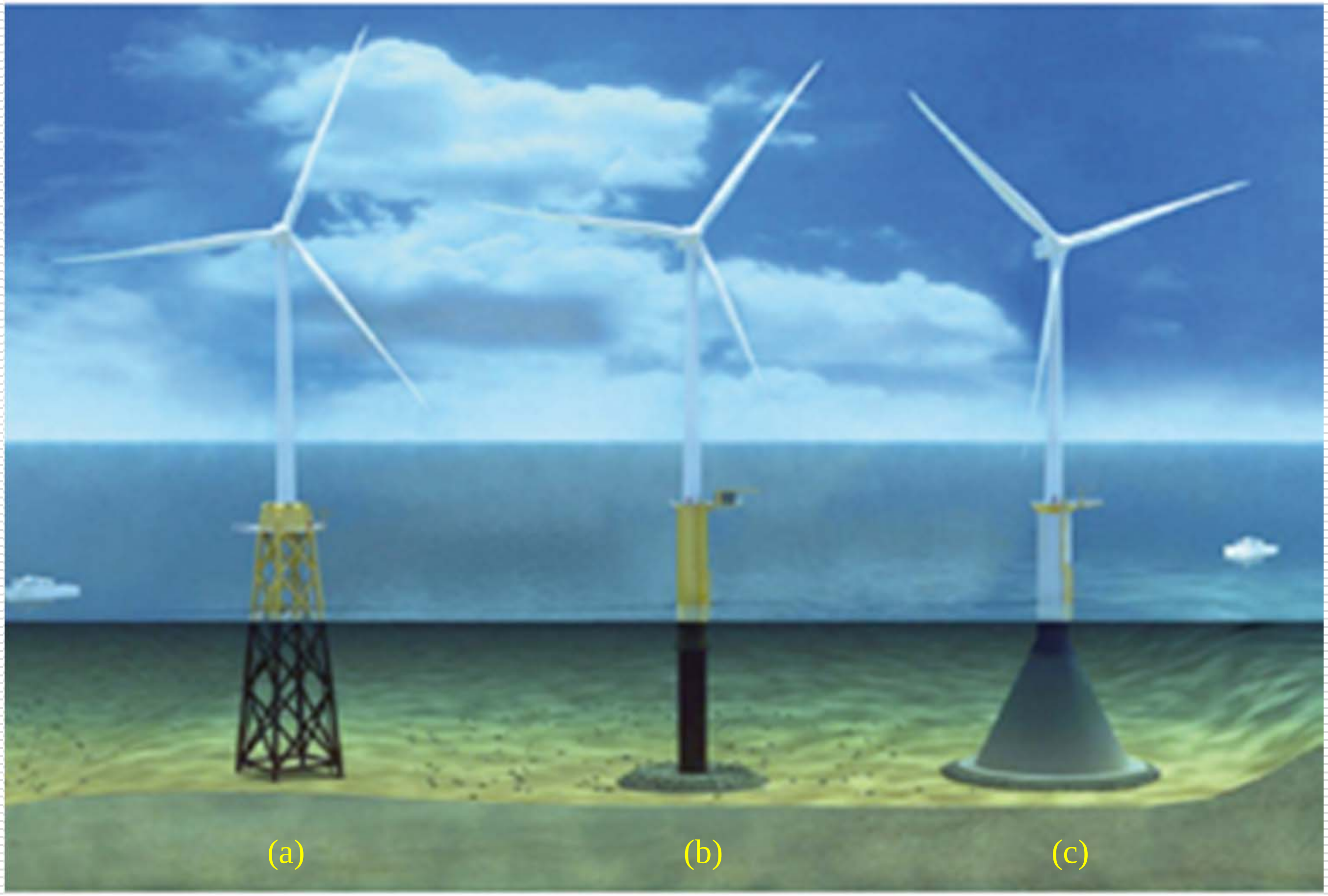
Offshore Structures



Bottom fixed foundation concepts (shallow water depth)
(a) Jacket; (b) Monopile; (c) Gravity base

Souce: www.offshorewind.org

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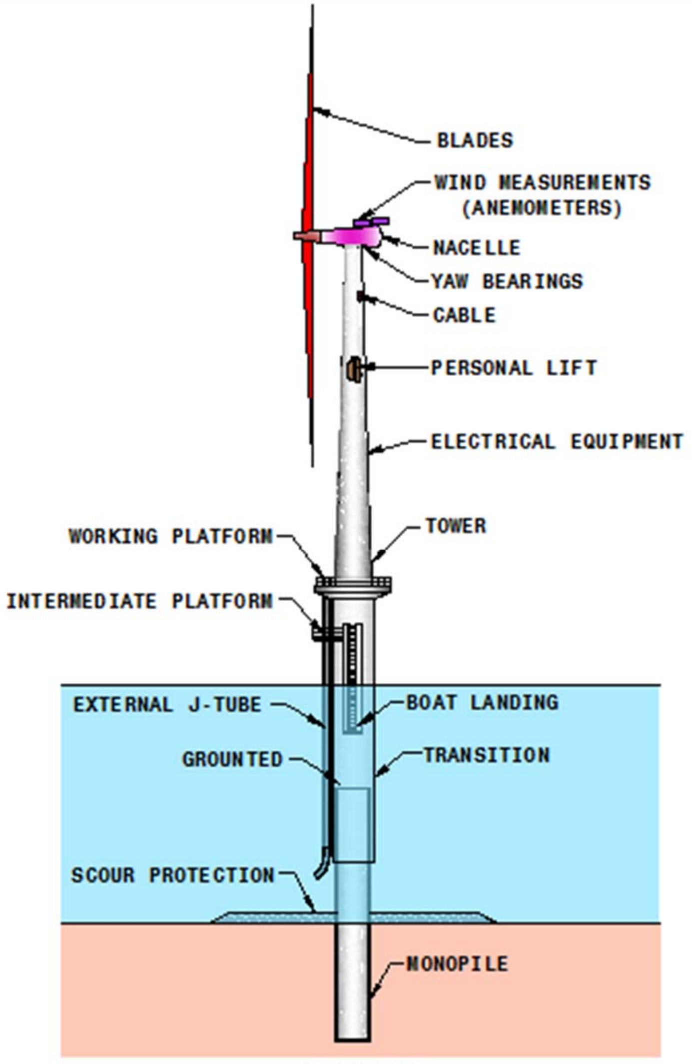
MONO PILE SUPPORT STRUCTURE

- Mono piles are the steel piles which are most widely used foundation type for wind turbine in shallow waters.
- Mono pile concepts involve driving of large diameter pile driven in to the sea bed for about 0-30 m deep to support the wind turbine from the single leg. This can be augmented by additional skirt piles in order to reduce large bending of mono piles.
- Nearly 70% of the installed wind turbines have used mono piles as their support structure.



MONOPILE

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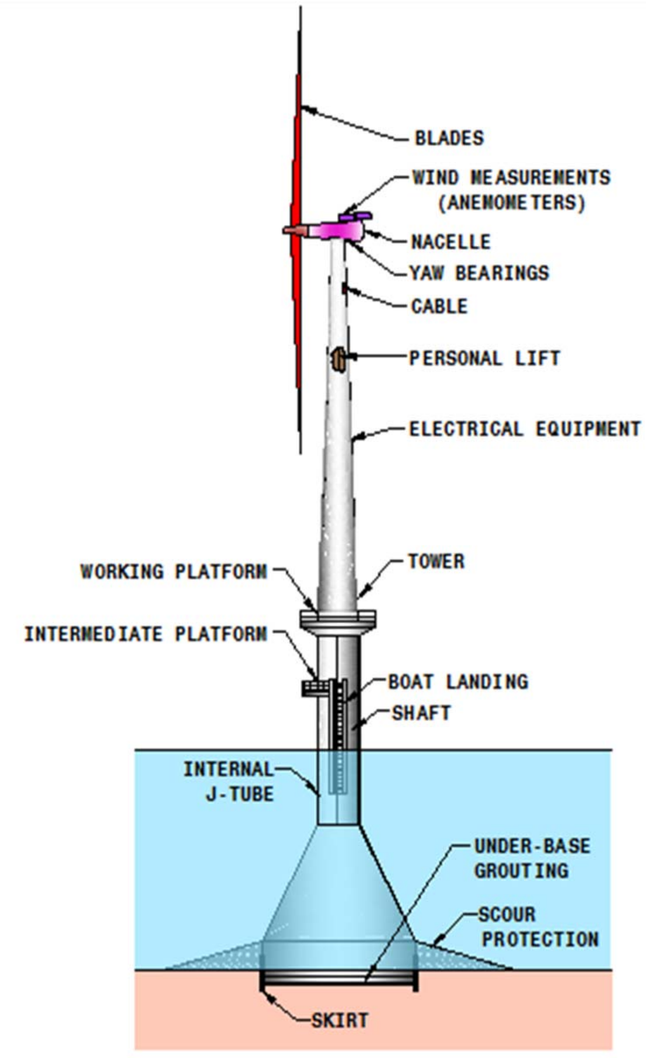
GRAVITY BASE SUPPORT STRUCTURE

- The gravity based structure is made up of concrete and heavy. Hence they are very stable and cost of construction is low.

- Mono piles and gravity base structures are used in the water depth of about 0-30 m.



GRAVITY BASE

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Near shore Structures

Advantages

- Near shore structures are bottom fixed structures.
- Construction technology is same as that of the onshore structures.
- Construction cost and time is low.
- Power grid connectivity is easy

Disadvantages

- Noise pollution causing disturbances to coastal areas.
- Disturbance to fishing boats and coastal transportation activity.

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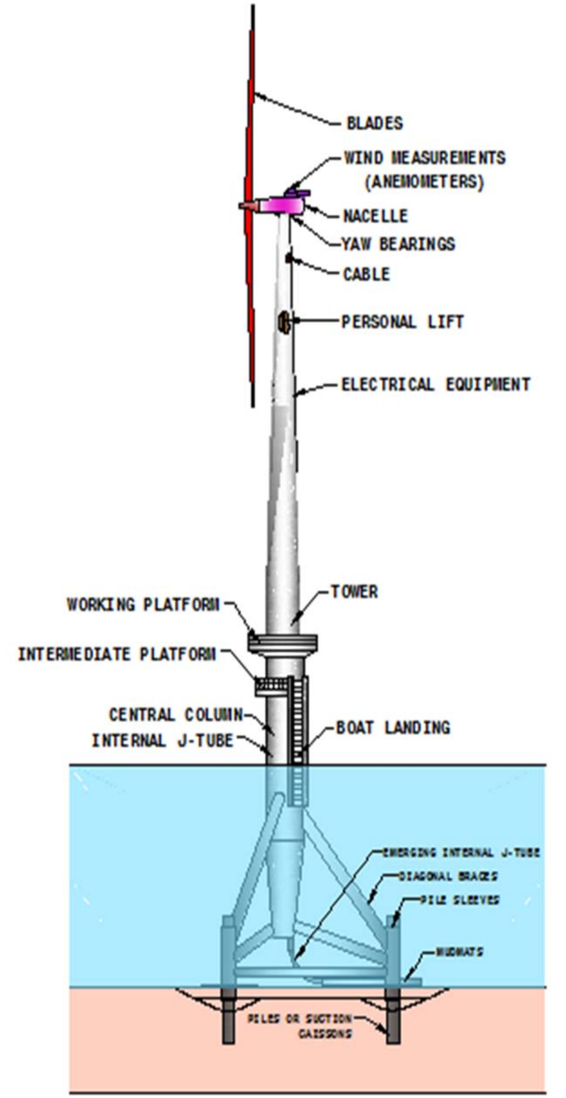
TRANSTITIONAL WATER DEPTH STRUCTURES

Tripod Support Structure

- The Tripod consists of a central column, diagonal bracings, and three supporting sleeves with mud mats.

- Through each sleeve is placed a pile, which is driven into the seabed and connected to the sleeve with concrete or grouting.



TRIPOD

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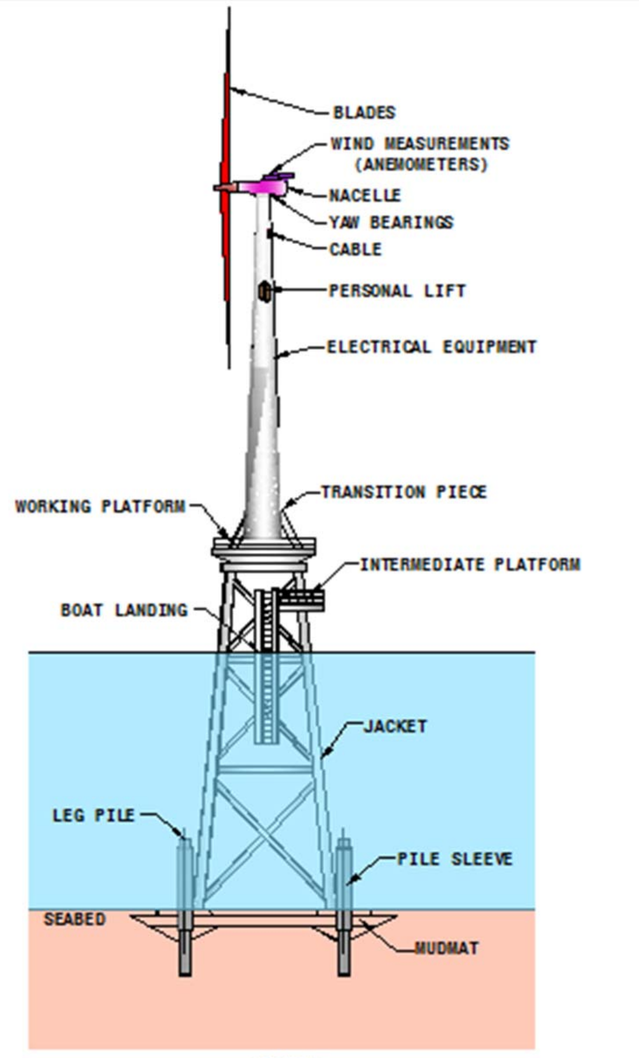
Offshore Oil and Gas Concepts

- Jacket type concepts involves 3 or 4 legs connected by bracings. The jacket legs are either battered or vertical.
- The jacket platform is used in case of little deeper water regions.
- Tripods and jacket support structures are used in water depth of 50-150m.



JACKET

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Wind Turbine Support Structures in Transtitional Water Depth

Advantages

- Support structures are bottom fixed structures.
- Construction technology used in oil and gas sector can be used as basis.
- No noise pollution causing disturbances to people in coastal areas.

Disadvantages

- Construction and installation cost is high.
- Time required for construction is relatively high.
- Power grid connectivity is an issue.

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FLOATING OFFSHORE WIND TURBINES

- Since the wind velocity is higher and continuous in offshore (far from coast)
- Floating support structures to wind turbines becomes essential as the water depth increases.
- Bottom fixed structures in deeper waters are not economically feasible.
- A huge percentage of the overall cost for installing an offshore wind farm goes into the construction and installation of the support structures.
- Therefore, to venture in offshore wind energy extraction it is important to obtain a suitable design for the structures that support the turbines, that are economically feasible too.

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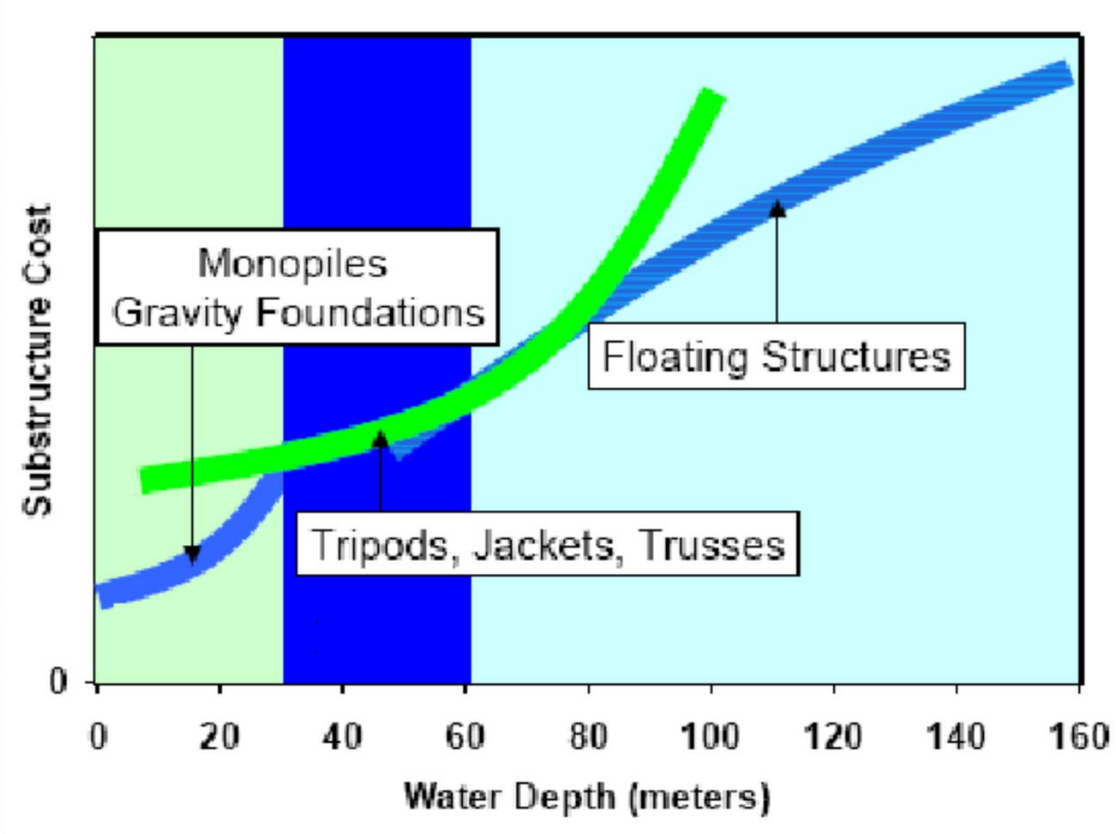
Offshore structures

- The development of the offshore wind energy depends on the substructures.
- As the water depth increases, the cost of offshore foundation increases due to the added complexity and resources needed below water line.



Source: NREL

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FLOATING OFFSHORE WIND TURBINES

- Typical offshore installation used for oil and gas exploration can be used as a basis to start the suitability of foundation concepts.

- The existing technologies developed for offshore oil and gas exploration can only be used to a limited extent since these does not consider the dynamic interaction of the wind turbine with the floating system and vice-versa.

- Hence there is an essential need to understand the system together to obtain the optimal operating condition for the wind turbine.

- The power connection with grid onshore is another challenge which may require to be carefully considered while estimation economical considerations.

- However, the design of such farms depends on the supporting foundation system as they will be subjected to environmental loads arising from severe wind, wave and current loads as they are located away from the coastline.

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CONCEPTS USED IN OTHER REGIONS OF THE WORLD

Mono piles in UK

Spar in NORWAY

Tri-floaters in USA

Source: www.wikipedia.org

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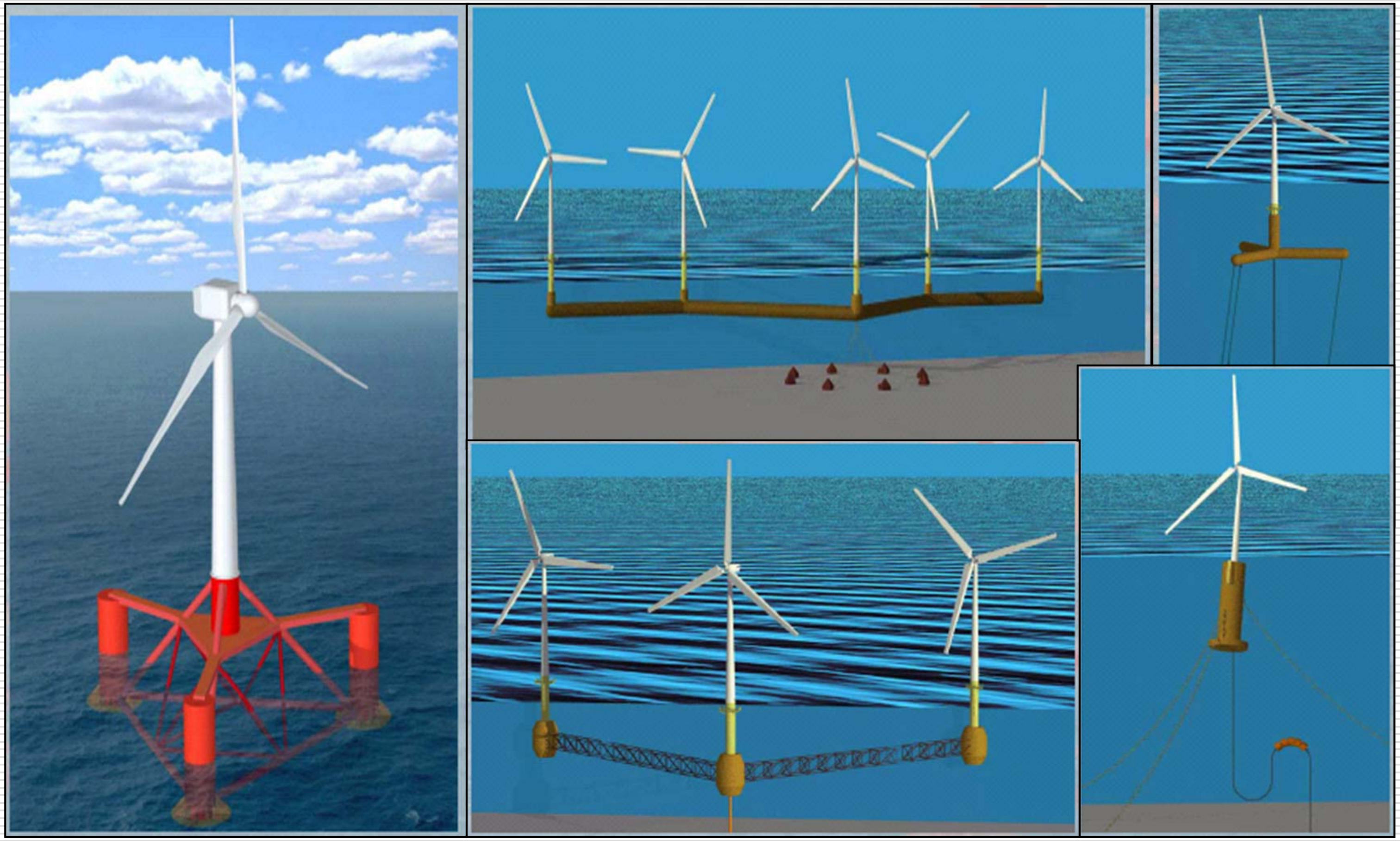
FUTURISTIC CONCEPTS



Source: TU Delft

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PROJECT EXECUTION

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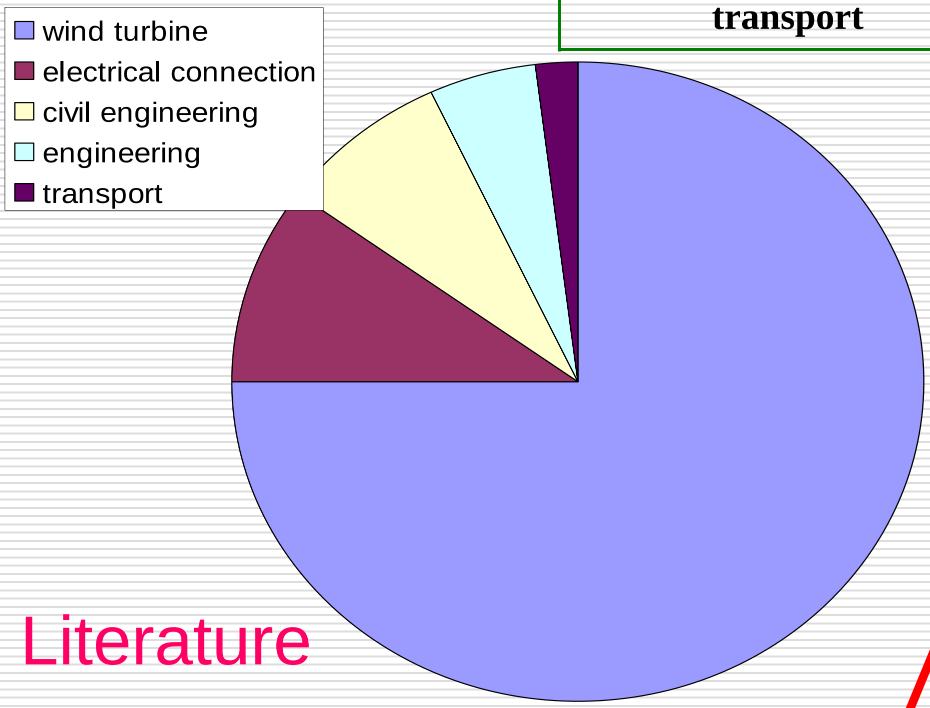
Relative cost distribution

Land based wind mill

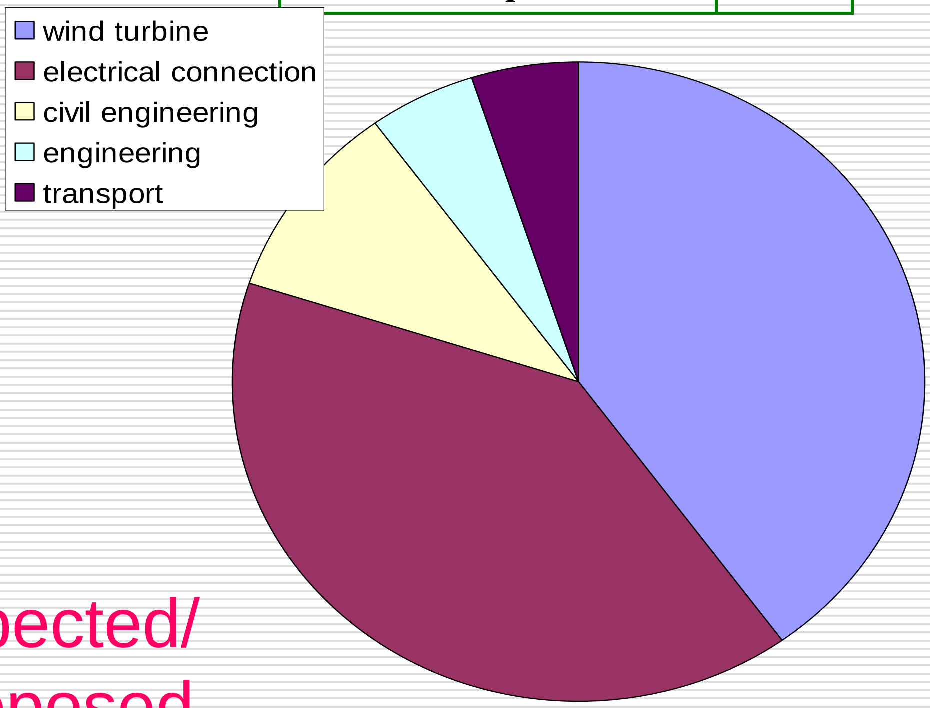
wind turbine	75%
electrical connection	10%
Foundation	8%
engineering	5%
transport	2%



Literature

offshore wind mill

wind turbine	40%
electrical connection	40%
Foundation	10%
engineering	5%
transport	5%



Expected/ Proposed

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Typical Installation

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COST OF OFFSHORE WIND TURBINE INSTALLATION (5 MW floating system)

Item Description	Cost (Rs Crores)	Cost (Million US$)
Wind Turbine (Nacelle and Blades) @ US$ 2M/MW	60.0	10.0
Tower & Floating Hull (800 Tonnes) @ US$ 3000/Tonnes	14.4	2.4
Anchors (4 Nos)	3.0	0.5
Mooring Lines (8 Lines)	3.0	0.5
Transportation (10 days @ 50,000/day)	3.0	0.5
Installation (5 days @ 300,000/day)	9.0	1.5
Total	92.4	15.4

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COST OF OFFSHORE WIND TURBINE INSTALLATION (5 MW Fixed Substructure)

Item Description	Cost (Rs Crores)	Cost (Million US$)
Wind Turbine (Nacelle and Blades) @ US$ 2M/MW	60.0	10.0
Tower & Foundation Structure (800 Tonnes) @ US$ 3000/Tonnes	14.4	2.4
Piles (4 Nos)	3.0	0.5
Transportation (10 days @ 50,000/day)	3.0	0.5
Installation (5 days @ 300,000/day)	9.0	1.5
Total	89.4	14.9

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Future Research Thrust Area

1) Innovative Foundation concepts for shallow and deep water considering the experience gained in Oil and Gas sector.

2) Economical solution to Power Transmission from Offshore to Onshore.

3) Wind turbines / locking mechanisms to sustain higher wind speed during cyclones ?.

4) Biological studies related to noise and marine life.

5) Coordinated effort by various governmental / non-governmental agencies ?

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Design Codes

1) DNV-OS-J101 – Design Of Offshore Wind Turbine Structures (2010)
2) API RP 2A WSD – Recommended Practice For Planning, Designing And Constructing Offshore Platforms – Working Stress Design (2005)
3) API RP 2A LRFD – Recommended Practice For Planning, Designing And Constructing Offshore Platforms – Load And Resistance Factor Design (1993)
4) Guidelines for the certification of offshore wind Turbines, Germanischer Lloyd (2005)
5) IEC 61400-3 Wind Turbines Part 3 : Design requirements for offshore wind turbines (2005)
6) Bundesamt Standard - Design of offshore wind turbines (2007)

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RECENT RESEARCH WORK AT IITMADRAS

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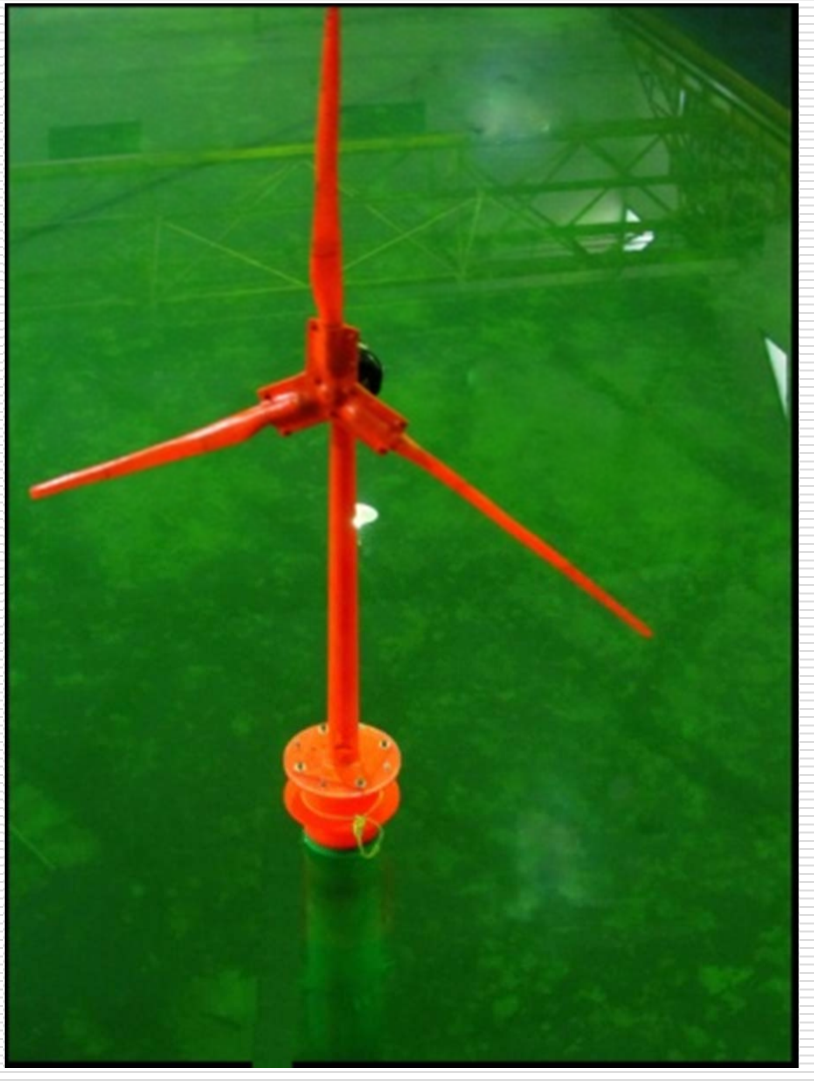
Interaction of Wind Turbine with Floating system

- Research work has been carried with the objective to investigate the dynamic response characteristics of Spar type support system for offshore wind turbine system and the coupled effect of wind turbine rotation on the response.

- Experimental and numerical work has been carried out to understand the interaction between the wind turbine and the floater system.



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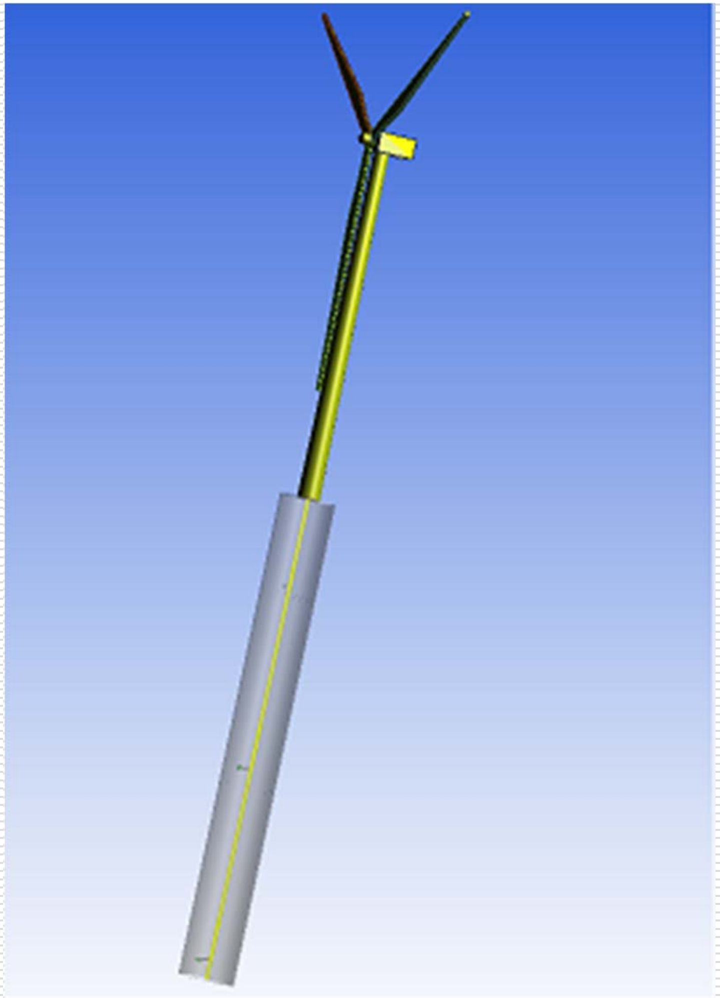
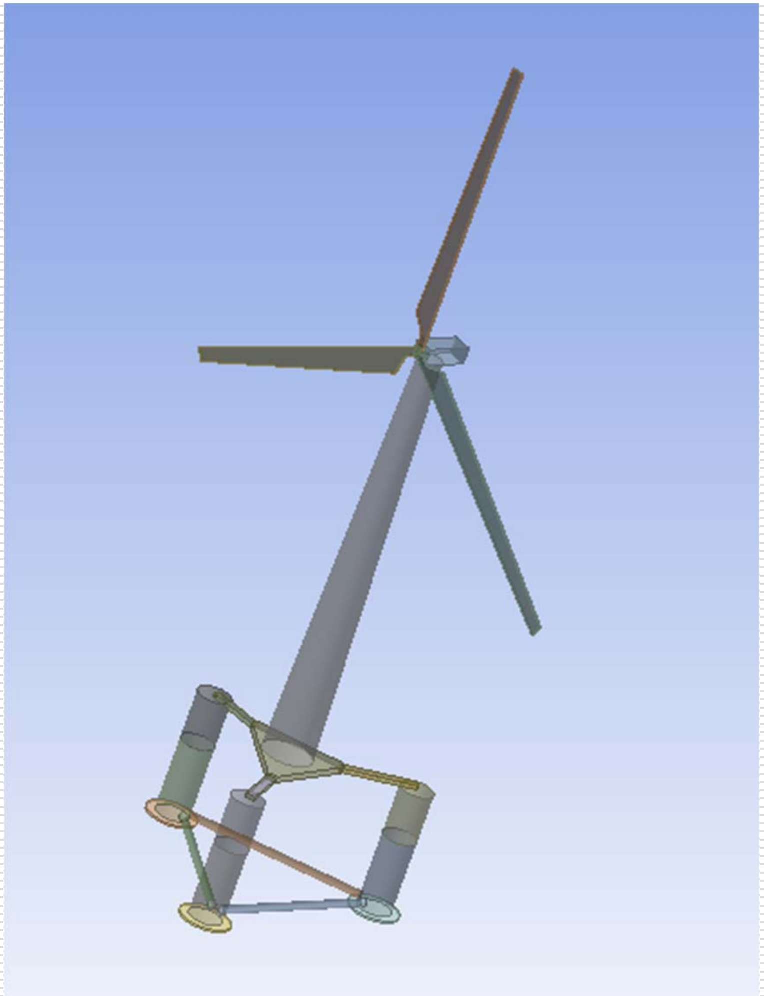
Simulation Models of Spar and Tri-floater supporting the wind turbine





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