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***Review Article***

# Science-based Technologies for Sustainable and Adequate Energy for India: Wind and Tidal Energy Sector

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Wind power in India accounts for about 8% of the total installed energy capacity in the country and is projected to grow at a fast pace. India today stands at 5th place in the world with regard to wind power utilization. The main technological barrier to exploitation of wind energy in India is that the country lies in low wind regimes, which calls for considerable changes in the design of turbine components and in the generator configuration itself to make them optimum for use in the Indian conditions. Most of the wind turbines operative in India are of foreign design or origin which may not be most suited for this purpose. A US-based study presents technology improvement opportunities for low wind speed turbines and associated cost and performance benefits, and hence is highly relevant to India. Further, India has a long coast line which presents tremendous opportunities for offshore wind energy harvesting. Some indigenous efforts have indeed been made towards wind mapping and suitable wind turbine design and development, but there are gaps in domestic capability that need to be plugged for better utilization of wind power. This article presents the current status of the wind power sector and discusses some of the concerned issues. Possible avenues for increased utilization of wind power in the country are also presented.

Tidal power has the potential to generate significant amounts of electricity at certain sites around the world. It is a valuable source of clean, renewable energy to an electricity supply system. The negative environmental impacts of tidal energy harvesting are probably much smaller than those of other sources of electricity, but are not well-understood at this time. The technology required for tidal power is well-developed, and the main barrier to increased use of tides is that of construction costs. The future costs of other sources of electricity, and concern over their environmental impacts, will ultimately determine whether humankind would extensively harness tidal energy. Tidal power in the Indian context is addressed taking into account the status, issues, concerns and challenges in the two sites at Sunderbans, West Bengal and Gulf of Kachchh, Gujarat. While tidal energy is a viable resource, it may prove to be expensive at first, but economical in the long run if the technology improves.

**Keywords: Wind Energy; Tidal Energy; Turbine; Rotor; Drive Train; Barrage; Cost of Energy; Offshore**

## 1. Wind Energy Sector

### 1.1 Introduction

It is reported that at the end of 2012, India was in the fifth position in the world with a total installed wind power capacity of 18,424 MW (megawatt), behind China, USA, Germany and Spain (GWEC, 2013). The Ministry of New and Renewable Energy (MNRE), Government of India (GoI) gives a figure of 19,779 MW of total installed capacity for India as on 31 August 2013 (http://mnre.gov.in/mission-and-vision-2/achievements). By the end of 2012, wind power was about 69% of the total installed renewable energy and 8% of total installed energy capacity in the country (GWEC, 2013). The Centre for Wind Energy Technology (C-WET), Chennai estimates the

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installable wind energy potential in India at 80 m level to be 102.778 GW (gigawatt) (http://www.cwet.tn.nic.in/). However, a study conducted by the Lawrence Berkeley National Laboratory (LBNL), USA estimated the same to be in excess of 2000 GW (Phadke *et al*., 2012).

Though India has significant wind power potential, there are several factors which constrain its optimum exploitation such as (i) its geographical and meteorological diversity, (ii) low wind speed regimes, (iii) dusty environment, (iv) non-availability of accurate data on wind and land use, (v) lack of adequate road infrastructure, (vi) lack of adequate indigenous effort in design and development, etc.

Most parts of India except parts of Tamil Nadu have low wind regimes (Class II (8.5 m/s)/III (7.5 m/s) wind speeds), which calls for considerable changes in the design of wind turbine systems for maximum exploitation of the available wind energy (GWEC, 2012). So, the success of an ‘India-specific’ wind turbine design will be judged on how effectively on a combined techno-economic basis, it can suit the relatively low wind speeds and a dusty/insect-laden environment with acceptable life cycle costs. Also, from an energy security angle, it is desirable that the design employs indigenous materials and technology. It may also be noted that India is also emerging as a major wind turbine manufacturing hub due to increased domestic demand, lower manufacturing costs and expansion of in-house manufacturing capacity with an annual production capacity of over 9500 MW as of 2012 ( GWEC, 2012). However, almost all the wind turbines installed so far in the country are of foreign origin, design or technology (http://www.cwet.tn.nic.in/; GWEC, 2012).

The following sections present different aspects with regard to the wind energy sector. In Sections 1.2 and 1.3, general aspects of wind turbine technology and components and cost breakdown of a typical wind turbine, respectively are highlighted. Section 1.4 presents the status of technologies used in wind turbines currently operative in India. In Section 1.5, technology trends towards reduction in cost of energy with reference to the important components of a wind turbine system and their manufacturing, based primarily on a report of a study carried out at the National Renewable Energy Laboratory, USA are presented (Cohen *et al*., 2008). Technologies relevant to offshore systems are presented in Section 1.6. In Section 1.7, indigenous wind turbine development programmes and the lessons learnt are discussed. The status of wind mapping in the country is presented in Section 1.8. The gaps in domestic capability and possible action plans to bridge the same are elaborated in Section 1.9, and Section 1.10 summarizes the conclusions of the study with regard to wind power.

### *1.2 General Aspects of Wind Turbine Technology*

In a typical horizontal-axis wind turbine, the power extracted from the flowing wind by the rotor is transmitted through a step-up gear box to the generator for conversion to electric power. The power, $P$ extracted by a wind turbine is proportional to the rotor swept area, $A$ and the cubic power of wind speed, $V$ (Grogg, 2005). Typically, the wind power density (WPD), which is the maximum wind power available per unit area, lies in the range of around 0-400 W/m$^2$, and a value of 200 W/m$^2$ is considered to be the threshold for harnessing. The sizing and costs of the wind power generation system are essentially determined by the size of the energy collector represented by the rotor swept area, $A$ for a given wind speed. It also indicates that for a given wind turbine, the power generated varies drastically with wind speed. It is thus important that the design wind speed is chosen carefully to ensure optimum performance of the wind turbine.

The cost effectiveness of a wind turbine generator, defined by the specific cost per kW (kilowatt) of energy generated, varies linearly with the diameter. Further, the gravity load on the blades and the turbine varies as the cube of the rotor diameter. Hence, while there is a trend towards larger rotor diameters permitting greater power capture for a given site (and corresponding wind speed), it must be noted that the weight and cost will also increase and there would be increasing complexities due to larger rotor deformations under load and difficulties in handling larger sized systems, all of which must be addressed through appropriate technologies and designs. On the other hand, higher hub heights (calling for taller towers) will allow taking advantage of higher wind speeds and less turbulence and also of sites with high wind shears.

### *1.3 Components and Cost Breakdown of a Typical Wind Turbine*

Conventional horizontal axis wind turbines (Fig. 1) consist of the following three components with corresponding cost breakdowns as percentage of total wind turbine cost (Grogg, 2005); (i) the rotor assembly which includes the blades and the hub, converting wind energy to mechanical energy (low speed rotation), the corresponding cost being about 20%, (ii) drive train and nacelle, consisting of low- speed and high-speed shafts, electrical generator, gear box, braking system and control electronics, all inside a nacelle, converting mechanical energy to electrical energy and

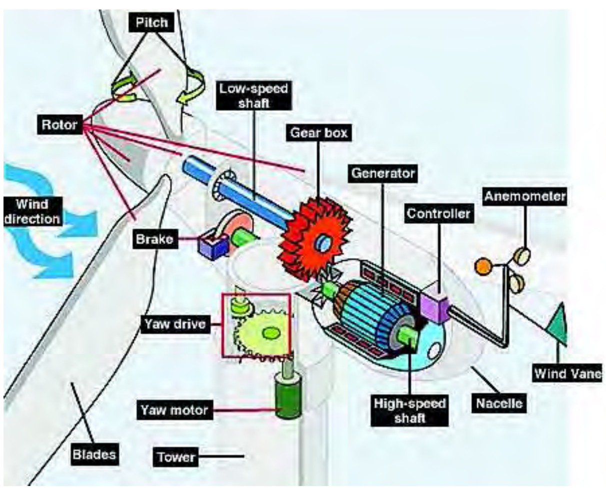



**Fig. 1: Components of a wind turbine. Source: http://en.wikipedia.org/wiki/wind/Wind-turbine**

contributing to about 34% of the cost, and (iii) the tower and the rotor yaw mechanism, which support the wind turbine and keep the rotor facing the wind , contributing to about 15% of the cost. It is thus seen that the wind turbine generator cost ((i) and (ii) above) is about 54% of the initial capital cost (ICC) and the turbine capital cost (TCC) is about 69% of the ICC.

### *1.4 Status of Technologies Used in Wind Turbines Currently Operative in India*

The most common features among the machines currently operative in India are as follows (http://www.cwet.tn.nic.in/; GWEC, 2012): (i) wind turbines of 1 MW class in the upwind, variable speed configuration, (ii) most of the machines are tuned to lower wind speed (Class II/Class III winds), (iii) blade diameter: mostly in the range 75-90 m, wind speed: 12-14 m/s, RPM (rotations per minute): 10-20, Hub height: 55-85 m, (iv) rotors have three blades, largely made of GFRP (glass fibre reinforced plastics) and use pitch control for speed/load control, (v) yaw control is employed to keep the rotors facing the wind, (vi) all use fixed towers, (vii) use both step-up geared (majority) as well as gearless drive train technologies, and (viii) variable rotor speed and a mixture of synchronous, asynchronous and double fed induction generators.

### *1.5 Technology Trends Towards Reduction in Cost of Energy*

On the advanced technology front, many technologies are being investigated abroad for their potential to provide an acceptable trade-off between lower costs, greater energy productivity, increased lifetime and durability and lower maintenance costs. The study presented by the National Renewable Energy Laboratory (NREL), USA (Cohen *et al*., 2008) is highly relevant to the Indian conditions as it deals with technology improvement opportunities (TIOs) for low wind speed turbines and associated performance and cost benefits, particularly from the point of view of minimizing the cost of energy (COE). Some of these considerations that are relevant to the Indian scenario are listed here with a view to draw maximum benefit while procuring off-the-shelf wind turbines or indigenously designing them. Inputs are also taken from Dayton *et al*. (2003) and Brian *et al*. (2008), particularly with regard to rotor design and manufacturing.

#### *1.5.1 Advanced Rotor Designs*

The approach here is to enlarge the rotor to increase its energy capture area without increasing structural loads. This is achieved through technology improvements in materials, structural-aerodynamic design, use of active and passive controls and higher tip speed ratios. Current rotor designs primarily use glass fibre reinforced plastics in their design with both laminate and sandwich (mostly with foam core) structural concepts. New material and material forms increasingly being considered are carbon fibres in large tows, new fabrics including 3D (3-dimensional) weaves, new toughened resins, thermoplastic resins, pultruded parts for spars, preforms (for resin infusion moulding), and integrated glass/carbon hybrids in thick sections with proper inter-lapping and ply-drop. In the Indian context, natural fibre composites may also be considered from eco-friendliness and cost point of view.

With regard to structural design, the conventional design uses either an I-beam or a box beam spar made of fibre-reinforced plastics to provide the required bending and shear strength and stiffness and a sandwich structure for the rest of the outer shell giving the aerodynamic shape. The TIOs include integrated design processes to optimize blades for (i) load capability, (ii) manufacturing ease and (iii) aerodynamic performance with design concepts such as simple internal structure, constant spar cap thickness and width, and high thickness flat back airfoils in the inboard half of the blade, and high lift airfoils with least complex and low cost internal structure for the outboard region.

Active and passive controls aim to reduce rotor loads to permit rotor diameter growth without overall system cost increase, but significantly decreasing turbine costs. These include active rotor collective and independent blade pitch control, use of adaptive control algorithms and active load mitigation techniques, and passive techniques such as building advantageous bend-twist coupling in the blades through proper aligning of carbon fibres.

Increasing rotor tip speed by increasing rotor rotation rate and simultaneously decreasing blade solidity by reducing blade chord (to reduce blade airloads and low speed shaft torque) will also contribute to reducing COE.

#### *1.5.2 Advanced, Cost-effective Manufacturing*

The open mould, wet lay-up processes are still used by several blade manufacturers. However, increasing environmental concerns with regard to processes with high emissions of volatile gases is driving the industry towards alternative processes such as resin infusion or use of pre-impregnated materials. Advancements in manufacturing will aim at reducing labour and material use and improved part quality. In the case of blades, automation of manufacturing processes will become necessary for larger blades. With regard to towers, onsite forming techniques for tower sections will reduce fabrication and transportation costs. Further, more consistent and reliable manufacturing processes will permit use of reduced safety margins in design due to reduced uncertainties.

#### ***1.5.3* Reduction in Energy Losses and Improved Availability**

Energy losses occur due to complete shut down or operation at less than the design output due to blade soiling caused by dusty environment, damaged sensors or control errors. Remedial measures are use of soiling tolerant airfoils, blade coatings that shed dirt, building-in quality control and fault tolerance in design, effective control systems that are capable of sensing off-optimal operation and adaptive adjustment, and incorporation of health monitoring systems (based on acoustic emission, optical fibres and advanced sensor technology) for continuous monitoring of the state of degradation of blades, drive train, generator and support structures.

#### *1.5.4 Advanced Tower Concepts*

The wind power industry is moving towards designs with taller towers (100 m or above) to be erected in more difficult locations without high lift capacity cranes and with possibility of fabrication/assembly/maintenance on site. These advanced towers will require new materials such as carbon fibre or E-glass, innovative structural concepts such as space frame designs, fluted towers or hybrid towers with combination of tubular and lattice configuration, new installation methods such as self-erection/de-installation without high lift capacity cranes and advanced foundations such as tension anchors.

### *1.5.5 New Drive Train Concepts*

Possible approaches for significantly advancing the state of drive train technology resulting in use of less material/reduced size and lower weight of support structure/less complexity, are using advanced gear profiles, integrated gear/generator systems, medium speed generators with permanent magnets (PMGs) in place of copper wound rotors (spinning at much lower speed compared to standard induction generators) coupled with a single stage gear box/single compound planetary stage gear box (delivering higher ratios that would normally require two stages) or alternative concepts such as multiple generators (having multiple drive paths with reduced design torque for each drive path) or direct drive generators (DDGs) which altogether eliminate the need for a gear box (with new high flux density, low cost permanent magnet design to reduce size and weight, power output conditioned by power electronics (PE), and segmented design for larger capacity machines).

Suggested TIOs to overcome bearing failure and lubrication depletion in gearbox are use of journal bearings, improved surface finishes and improved analytical methods, lubricant additives to resist depletion, and lubricant quality sensors for early detection of gear/drive train failure**.** Other future considerations in generator design/selection are higher generator efficiency at lower than design power levels, high voltage designs, use of generators with axial flux paths, active cooling systems with water or hydrogen, air cooling, use of superconducting generators, and high flux density magnets.

### *1.5.6 Advanced Power Electronics*

Power Electronics is becoming an increasingly important part of modern wind turbine designs. As more single-stage, direct drive permanent magnet generators are developed, PE will be used to process and condition turbine power. Also, PE will permit control of factors such as low voltage ride through, reactive power, voltage, and ramp rate needed for greater range of grid compatibility. Further, PE can also be used to integrate energy storage and hydrogen production into the wind turbine or wind farm. Advanced PE can incorporate technologies such as new circuit topology/design, new semiconductor devices, new materials (GaAs, SiC, diamond, etc.) and new ways of connecting thousands of switching devices leading to higher utilization efficiency and larger voltage/current handling ability.

### *1.5.7 Overall Assessment*

The overall assessment was that primary contributions to potential COE reduction come from advanced rotors and site specific design/reduced design margins, the latter due to taking maximum advantage of local wind conditions at the site. It was projected by Cohen *et al*. (2008) that in the reported study, with reference to the reference turbine, TIOs described here could result in overall 23% reduction in COE with 95% confidence level and 37.5 reductions in COE (original goal) with 46% confidence level. Such considerations must be kept in mind while importing off- the-shelf machines from abroad or indigenously designing and developing wind turbines in the country for future use.

### *1.6 Technologies Relevant to Offshore Systems*

India has a coastline of over 7500 km which presents prospects of significant offshore wind power development. MNRE, Government of India has prepared a 'National Offshore Wind Energy Policy - 2013' to enable optimum exploitation of offshore wind energy with a time-bound action plan. While the majority of the design features and technologies used in the on-land wind turbines are also applicable to offshore systems, there are distinctive features of the offshore scenario that will have an impact on the design of offshore systems. These are (Grogg 2005; Transport Research Board, 2011; Kothari and Umashankar, 2012): (i) Higher and more consistent wind speeds and larger site availability leading to higher capacity wind turbines (3-5 MW at present but expected to go up to 8-10 MW) with larger rotor diameters (in the range of 90-130 m at present, but greater than 150 m in future) and higher efficiency. In this context, it may be noted that current offshore WPDs are around 400 W/m$^2$. (ii) Higher tip speeds are possible as there is less constraint on acoustics emission levels, but adequate tower clearance of blade tips may be a problem as blades become longer and more flexible. (iii) Relatively large distances to the coast make grid connections more complex and expensive and the deep water makes expensive foundations necessary. The result is that one must get the highest possible yield out of every single turbine to keep the COE low (currently 1.5-3 times that of land-based systems). (iv) Special attention is required to develop the pile foundation technologies (monopile for shallow waters and multiple driven piles such as tripods and jackets for transition depths of 30-60 m) and several such innovative concepts (reinforced concrete gravity-base foundations, suction caissons, etc.) to withstand the severe axial and lateral loading in the ocean environment. Floating type foundations (semi-submerge/spar buoy) are an alternative to fixed foundations. (v) Greater emphasis on reliability (including environmental controls to protect critical drive train and electrical components, upgrades to electrical systems) and access (personnel access platforms for maintenance/emergency shelter) is needed. (vi) Strengthening of the tower to handle added loading (including fatigue loading) from the waves, pressurization of the nacelles, etc. Remote sensing and condition monitoring assume greater importance in this context to reduce operational costs and yield better maintenance diagnostic information. (vii) Corrosion resistant materials and preventive coatings are necessary to counter corrosive effects of the saline atmosphere. (viii) Importance of surface wave patterns – technologies to examine and assess the generation and development of waves, and the nature and mathematical description of the sea states. (ix) Experiences gained from oil and gas industry may be translated including methods of installation and monitoring.

### *1.7 Indigenous Wind Turbine Development Programmes and the Lessons Learnt*

The only major indigenous effort at design and development of wind turbines to suit the Indian conditions was at the CSIR (Council of Scientific and Industrial Research) - National Aerospace Laboratories (CSIR-NAL), Bangalore in partnership with CSIR- Structural Engineering Research Centre (CSIR-SERC), Chennai and an industrial partner, the Sangeeth Group, Coimbatore (Dayanand, 2013). The group embarked on the design and development of a 500 kW class horizontal axis, grid-connected wind turbine under a CSIR-NMITLI (New Millennium Indian Technology Leadership Initiative) programme during the 11th Five Year Plan. The wind turbine was a 2-bladed, stall-regulated, teetered, downwind machine on a guyed tilt-tower to allow for easy access to the blades for maintenance and R&D studies. It had a design wind speed of 12 m/s, rotors of diameter of 45 m at a hub height of 60 m, rotating at 23 rpm. The GFRP blades had advanced airfoils specially developed by CSIR-NAL. The turbine speed was regulated by aerodynamic tip brakes made of Carbon Fibre Composite (CFC) and mechanical disk brakes working on the high speed shaft. The drive train consisted of a two-stage planetary gear box and an asynchronous induction generator with 1500 rpm. It was successfully installed in a wind farm in Kethanur in Tamil Nadu and operated in the windy months during 2009-12 and was connected to Tamil Nadu Electricity Board Grid. This was India’s first fully indigenous medium-scale wind turbine and its limited trials indicated success of the approach. The size of the turbine made it easier to transport and install and the fact that it was two-bladed and on a tilt tower made it easier to install and uninstall as required for testing/ maintenance. This wind turbine could serve as a model for possible future variants to meet India’s specific needs.

Besides, CSIR-NAL has an ongoing developmental programme, supported by an industrial partner, of a 0.5 kW class micro wind turbine (http://www.nal.res.in/pages/ipjul12.htm; http://nal-ir.nal.res.in/10074/). The in-house developed small wind turbine with four CFC blades is integrated with solar panels to realize a wind–solar hybrid system. According to CSIR-NAL, field trials have shown excellent sustained performance including improved performance at low wind speeds (2-10 m/s) compared to a commercial turbine of equivalent class.

The CSIR-NAL model for indigenization of wind turbine systems and technologies, involved a conscious decision to closely collaborate with MSMEs (micro, small and medium enterprises) in the private sectors across the country for the supply of component systems and services with required quality, ruggedness and reliability.

### *1.8 Wind Mapping*

Wind mapping over different regions of the country will establish the national wind resources potential and help in identifying suitable sites for efficient and economically sustainable wind energy harnessing. The Indian Wind Atlas (C-WET and Riso DTU, 2010) presents such a data, including both regional assessment over large regions and wind siting at specific locations. Maps in the atlas show mean simulated wind speed and mean simulated WPD at 80 m a.g.l (above ground level) over the country including offshore regions up to a distance of 100 km from the coast.

By the end of 2013, a total of 777 dedicated wind monitoring stations had been commissioned in 28 states and 3 union territories in the country (http://cwet.tn.nic.in/Docu/list_of_WMS_on_31_12_2013.pdf). Overall, 236 stations showed MAWPD (mean annual WPD) in excess of 200 W/m$^2$ which makes them suitable for wind farming as per the existing criteria in the country.

### *1.9 Gaps in Domestic Capability and Proposals to Bridge the Gaps*

Although considerable progress has been achieved in harnessing wind energy in the country, certain critical gaps still exist in the domestic capability as explained here, which need to be plugged to exploit the wind energy potential to its fullest extent (INAE and The IIM, 2014; CSTEP 2013; GWEC, 2012):

(i) The *Indian Wind Atlas*, though a comprehensive guide for wind resources in the country, has certain limitations on its full applicability to the Indian conditions due to (a) the relevance to the Indian conditions of the assumptions made, particularly with regard to terrain roughness, orography and shelter effect, surface fluxes, land availability, etc., and (b) the approaches used, particularly with respect to calibration of numerical models with actual measurements which may be inadequate. These limitations need to be overcome with India-specific data and approach.

(ii) Wind as a resource is characterized by both variability and unpredictability leading to substantial diurnal variations in power output which can create problems for the traditional grids in maintaining a supply and demand balance. Hence, the grid should have the capability to absorb this variation by backing down/ramping up other quick ramping generating sources as required. Also, excess of wind power can be efficiently handled by diverting to appropriate storage devices such as advanced batteries and compressed air storage systems which need to be developed. Further, the above mentioned operations for maintaining smooth grid operation and stability call for establishing an indigenous capability for now-casting (i.e., forecasting features of wind power patterns with reasonable accuracy within the next three to six hours). Now-casting will enable a ‘‘smart’’ electrical grid to optimally manage the different sources of energy viz., thermal, solar, wind, hydro and nuclear power.

There is thus great scope for using weather and climate informatics for efficient and commercially sustainable wind energy generation, though there are many difficulties and challenges in effective planning for utilization of wind energy because of the large diversity of climate and geography over the Indian peninsula and associated regional variations. The challenges are (a) establishing a network of monitoring stations of reasonable density and (b) evolving tools of simulation, assimilation and analysis appropriate to Indian tropical climate conditions and geography and local orographic and surface conditions with desired spatial resolution. Meeting these challenges effectively will help develop a high-resolution wind energy atlas over India. Capability must also be established to model the flows (atmospheric boundary layer, etc.) with a cluster of wind turbines in a wind farm at desired horizontal and vertical resolutions for optimum design/selection of turbines and their stacking leading to increased stacking density using different hub heights and inter-cropping.

(iii) There is a need for enhancing indigenous design and development capability for wind turbine systems optimally designed for the low speed wind Indian conditions. At present, the wind turbine generators installed in India with imported design/technology would operate at 1/3 to 1/2 of their rated capacities for the maximum duration of any year, pushing the capacity utilization factor (CF) to a low level (http://www.cwet.tn.nic.in). The CF of wind turbine generators in India is in the range of 17-24% and the electricity generation from wind is about 3-4% of the net electricity generation from all sources as compared to 7% in Europe, 5.5% in UK and 3.5% in USA.

(iv) On the whole, there is an acute lack of adequate design capability and human resources in all the segments of this area in the country. R&D programmes for technology improvement specific to the industry needs are lacking. There is an urgent need to include wind turbine design and technologies in the post-graduate curriculum and to support R&D efforts of the kind initiated at CSIR-NAL in more R&D laboratories with active participation from the industry.

(v) On the materials and manufacturing side, although many manufacturers have set up their manufacturing and assembly facilities in India, in critical components such as blades, gears, generators and controls, about 60% import content is still present. Use of materials such as high nitrogen steels, high strength steels in the construction of wind turbine systems must be explored. Indigenous capability in rare earth materials for use in generators, high strength glass and carbon fibres and their hybrid composites for turbine blades, nano technology for improving blade fatigue strength, use of low cost, eco-friendly and locally available materials such as natural fibres and resins, materials and processes for improving corrosion resistance, etc. need to be developed. Materials and component manufacturers and suppliers in the country are capable of meeting the requirements but need to be enabled with encouragement and support to bring in quality and reliability.

(vi) India still needs to establish an interlinked and unified grid through integration of its local, regional and national grids (GWEC, 2012). Often inadequate and weak grids act as a barrier to smoother integration of power generation from renewables. Lack of adequate evacuation capacity in the state grids is a major concern in transmission planning which makes state distribution utilities reluctant to accept more wind power generation.

### 1.10 Conclusions: Wind Power

India has significant wind power potential and presently occupies the fifth position in the world in its harvesting. One of the factors limiting its exploitation is the fact that most regions of India lie in low speed wind regimes. This calls for wind turbine systems specially designed for Indian conditions for optimum exploitation of available wind power. Most of the wind turbines operative in India are of foreign design or origin which may not be most suited for this purpose. A study by NREL, USA presents technology improvement opportunities for low wind speed turbines and associated cost and performance benefits, and hence is highly relevant to India. Relevant aspects of this study dealing with advanced rotor designs, manufacturing, tower concepts, drive train and power electronics are required to be adopted here. Further, India has a long coast line, which presents tremendous opportunities for offshore wind energy harvesting. Hence, technologies relevant to offshore systems need to be pursued and the vast offshore potential needs to be exploited with a focused and concerted national action plan. Lastly, there is a need to scale up and also accelerate the indigenous design and development efforts taking note of the lessons learnt from the earlier efforts and of the gaps in technology in the various segments of the industry. It is, however, clear that enough knowledge, expertise and experience is available in the country in this important area and with encouragement and support, desired progress can be achieved within a short period of time.

## 2. Tidal Energy Sector

### 2.1 Introduction

Ocean produces two types of energy: thermal energy from the sun's heat, and mechanical energy from the tides and waves. The fact that the marine renewable sector is less developed than other energy industries presents both opportunities and challenges. The lack of an established industry structure can make entry into the market uncertain for newcomers. However, this lack of structure also means that potentially there are more opportunities than in other segments of the energy industry that are already developed and more mature (http://mnes.nic.in). A wide range of companies are involved in the marine renewable sector.

Tides are generated through a combination of forces exerted by the gravitational pull of the sun and the moon and the rotation of the earth. The relative motion of the three bodies produces different tidal cycles which affect the range of the tides. In addition, the tidal range is increased substantially by local effects such as shelving, funneling, reflection and resonance. Energy can be extracted from tides by creating a reservoir or basin behind a barrage and then passing tidal waters through turbines in the barrage to generate electricity. Tidal energy is extremely site-specific and requires mean tidal differences greater than 4 metres and also favourable topographical conditions such as estuaries or certain types of bays in order to reduce the cost of dams etc., (http://www.cii.in). Since India is surrounded by sea on three sides, its potential to harness tidal energy has been recognized by the Government of India.

### *2.2 Types of Tidal Plants*

***2.2.1 Barrage Tidal Plants*: ** Barrage tidal plants are the most common type of tidal plants. A dam or barrage is installed (Fig. 2), usually where there is a narrow water channel, with gates and turbines at certain points. As the water flows through the turbines, it turns a generator that produces electricity.

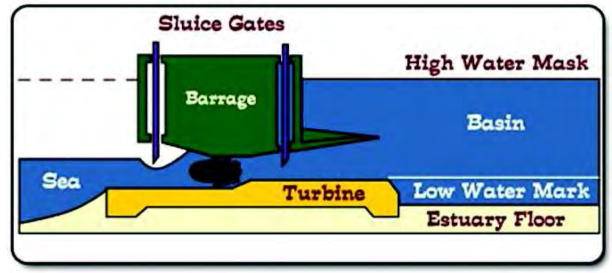



**Fig. 2: Schematic of a tidal barrage. (http://www.esru.strath.ac.uk/EandE/Web_sites/01-02/RE_info/Tidal%20power%20files/image004.jpg)**

With a barrage, water can spill over the top or through turbines in the dam because the dam is low. Barrages can be constructed across tidal rivers, bays, and estuaries (Khan *et al*., 2008). Turbines inside the barrage harness the power of tides in the same way as a river dam harnesses the power of a river. The barrage gates are open as the tide rises. At high tide, the barrage gates close, creating a pool, or tidal lagoon. The water is then released through the barrage's turbines, creating energy at a rate that can be controlled by engineers through appropriate control systems.

The Energy $E$, stored in a tidal barrage is given by $E = (1/2)gA\rho h^2$, where '$g$' is the acceleration due to gravity, '$A$' is the horizontal area of the barrage basin, '$\rho$' is the density of water and '$h$' is the vertical tide range. The environmental impact of a barrage system can be quite significant. The landscape in the tidal range is completely disrupted. The change in water level in the tidal lagoon might harm plant and animal life. The salinity inside the tidal lagoon lowers, which changes the organisms that are able to live there. As with dams across rivers, fish are blocked into or out of the tidal lagoons. Turbines move quickly in barrages, and marine animals can be caught in the blades (http://www.geni.org). With their food source limited, birds might migrate to different places.

A barrage is also a much more expensive tidal energy generator compared to a single turbine. Although there are no fuel costs, barrages involve more construction and more machines. Unlike single turbines, barrages also require constant supervision to adjust power output.

***2.2.2 Tidal Fences*:** Tidal fences block a channel, forcing water to go through it and turning its turbines to generate electricity.

***2.2.3 Tidal Turbines*:** Tidal turbines work similar to an underwater wind turbine, using the tides to turn blades and generate electricity.

### *2.3 Working of a Barrage Tidal Plant*

There are three main parts in a barrage tidal plant (Fig. 3A&B). These are:

a. Barrage, which acts much similar to a dam, holding back water to be released later

b. Sluice gates, which allow water to flow through the turbine

c. Turbine, which spins as the water flows through it, rotating an electricity-producing generator.

When the tide rises, it will be first held back in the barrage and then released into the estuary; flowing through a turbine and causing it turn a generator, producing electricity. Later, when the tide falls, water behind the barrage is held in the estuary. The water is then released, flowing seaward and turning another turbine and generator, allowing the electricity-producing process to be repeated.

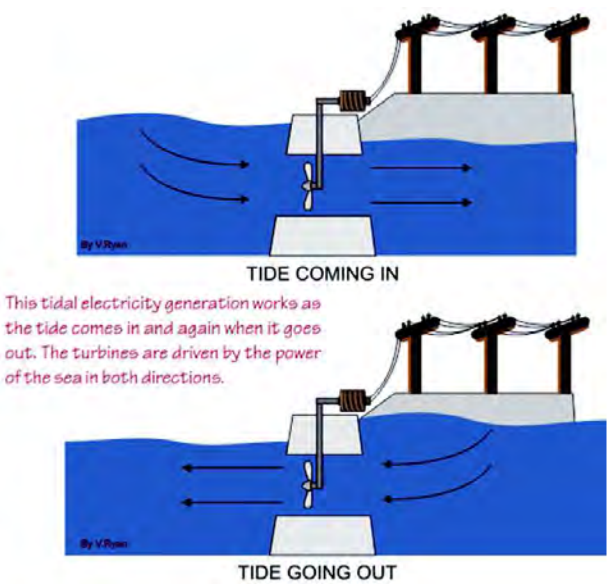
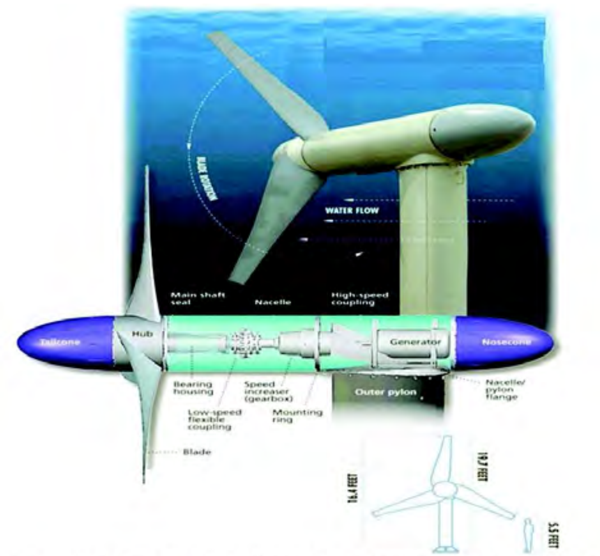



**Fig. 3: (A&B) Barrage tidal plants. Source: Ryan, 2008; (http://2.bp.blogspot.com/_b5hcKABPlGI/TI2Il1-juVI/AAAAAAAAidc/xd1ZfJCJU7I/s1600/9-1310e.png)**

A tidal turbine functions similar to a wind turbine under water (Fig. 4). The ocean's currents rotate the turbine blades turning a generator that converts the energy into electricity which is transmitted onshore by underwater cables. The turbines are mounted on pylons affixed to the sea floor or river bottom. The pylons contain bearings that allow the turbines to pivot so that they can catch the tide in both the directions.




Source:Devine Tarbell & Associates, Verdant Power,images courtesy of Verdant Power

**Fig. 4: Tidal turbine configuration. Source: http://www.verdantpower.com**

### *2.4 Tidal Power: Advantages and Disadvantages*

| Advantages | Disadvantages |
|---|---|
| Does not generate emissions or wastes | Expensive to construct |
| Uses an abundant, inexpensive fuel source (water) to generate power | Power is often generated when there is little demand for electricity |
| Electricity is reliably generated (tides are predictable) | Limited construction locations |
| May protect coastline against damage from high storm tides and provide a ready-made road bridge | Barrages may block outlets to open water. Although locks can be installed, this is often a slow and expensive process. |
| | Barrages affect fish migration and other wildlife – many fish such as salmon swim up to the barrages and are killed by the spinning turbines. Fish ladders may be used to allow passage for the fish, but these are never 100% effective. Barrages may also destroy the habitat of the wildlife living near it. |
| | Barrages may affect the tidal level – the change in tidal level may affect navigation, recreation, cause flooding of the shoreline and affect local marine life |

Source: http://www.virtualsciencefair.org/2006/wong6j2/tidal.html

### *2.5 Technology of Tidal Power Generation*

A tidal barrage is a way of converting the energy of tides into electric power. It works in a way similar to that of a hydroelectric scheme, except that in the latter case, the dam is much bigger and spans a river estuary. As stated earlier, when the tide goes in and out, the water flows through tunnels in the barrage (Arvizu, 2007). The ebb and flow of the tides can be used to turn a turbine, or it can be used to push air through a pipe, which then turns a turbine.

#### *2.5.1 Global Scenario*

Advances in materials science to develop high strength, lightweight materials for turbine blades and towers are required in order to facilitate the construction and continued operation of large tidal power turbines. Long lasting protective coatings will also be required to reduce maintenance costs and prolong the operating life of tidal energy devices. Globally, tidal energy production is still in its infancy and the amount of power produced so far has been rather small.

#### *2.5.2 Tidal Energy Generators*

There are currently three different ways of producing energy from the tides: tidal streams, barrages, and tidal lagoons. Tidal barrages is already described here.

(a) *Tidal Streams*: In most tidal energy generators, turbines are placed in tidal streams. A tidal stream is a fast-flowing body of water created by tides. As water is more denser than air, tidal energy is more powerful than wind energy. Unlike wind, tides are predictable and stable. Where tidal generators are used, they produce a steady, reliable stream of electricity.

The power $P$, generated in a tidal stream generator is given by $P = (1/2)çAñV^3$, where '$ç$' is the turbine efficiency, '$A$' is the turbine swept area, '$ñ$' is the density of water and '$V$' is the flow velocity.

Placing turbines in tidal streams is complex, because the machines are large and disrupt the tide they are trying to harness. The environmental impact could be severe, depending on the size of the turbine and the site of the tidal stream (Bedard, 2008). Turbines are most effective in shallow waters. This produces more energy and also allows ships to navigate around the turbines. A tidal generator's turbine blades also turn slowly, which helps marine life avoid getting caught in the system. The world's first tidal power station was constructed in 2007 at Strangford Lough in Northern Ireland, with the turbines being placed in a narrow strait between the Strangford Lough inlet and the Irish Sea. The tide could move at 4 metres (13 feet) per second across the strait.

(b) *Tidal Lagoon :* This type of tidal energy generator involves the construction of tidal lagoons. A tidal lagoon is a body of ocean water that is partly enclosed by a natural or manmade barrier. Tidal lagoons might also be estuaries and have freshwater emptying into them. A tidal energy generator using tidal lagoons would function much similar to a barrage. Unlike barrages however, tidal lagoons can be constructed along a natural coastline. A tidal lagoon power plant could also generate continuous power. The turbines work both as the lagoon is filling and as it is emptying.

The environmental impact of tidal lagoons is minimal. The lagoons can be constructed with natural materials such as rock. They would appear as a low breakwater (sea wall) at low tide, and be submerged at high tide (Bedard, 2007). Animals could swim around the structure, and smaller organisms could swim inside it. Large predators such as sharks would not be able to penetrate the lagoon, so smaller fish would probably thrive. Birds would likely flock to the area.

However, the energy output from generators using tidal lagoons is likely to be low. There are no functioning examples yet. China is constructing a tidal lagoon power plant at the Yalu River, near its border with North Korea. A private company is also planning a small tidal lagoon power plant in the Swansea Bay in Wales.

#### *2.5.3 The Next Generation Marine Turbine*

The next generation marine turbine, the transverse horizontal axis water turbine (THAWT) developed by the Oxford University Engineering Department is shown in Fig. 5 (Bedard, 2008; 2007). While the conventional turbines operate similar to windmills and must be turned with the tides, the THAWT configuration works equally well with flow from either direction and hence requires no adjustments as the tide changes direction (Guy, 2011). It can also be easily scaled and requires fewer foundations, bearings, seals and generators than a more conventional axial-flow device. It is also more robust and so can be larger in size, harnessing more of the energy of flow with outputs more than 50% higher than those achievable by propeller-type turbines placed in the same site. A full-scale device might have a diameter of 10-20 m, length of about 60 m and would operate in a flow depth of 20-50 m. Further, multiple THAWT rotors can be chained together across the width of a channel (McAdam, 2009).

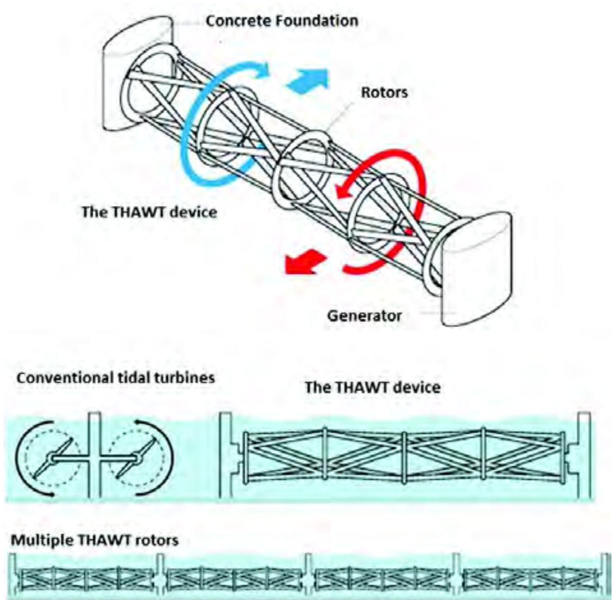



**Fig. 5: Transverse horizontal axis water turbine (THAWT). Source: http://www.inhabitat.com/wp-content/uploads/turbine1.jpg; McAdam (2009)**

### *2.6 Potential of Tidal Energy in India*

The most attractive locations for tidal energy in India are the Gulf of Cambay and the Gulf of Kachchh on the west coast where the maximum tidal range is 11 m and 8 m, with average tidal range of 6.77 m and 5.23 m, respectively. The Ganges Delta in the Sunderbans in West Bengal also has good locations for small-scale tidal power development. The maximum tidal range in Sunderbans is approximately 5 m with an average tidal range of 2.97 m.

The identified economic tidal power potential in India is of the order of 8000-9000 MW with about 7000 MW in the Gulf of Cambay, about 1200 MW in the Gulf of Kachchh and less than 100 MW in Sundarbans.

#### *2.6.1 Proposed Tidal Power Projects in India*

The Ministry of New and Renewable Energy announced in February 2011 that it may provide financial incentives as much as 50% of the cost for projects seeking to demonstrate tidal power (http://www.teriin.org).

(a) *Kachchh Tidal Power Project* : In 1970, the CEA had identified this tidal project in the Gulf of Kachchh in Gujarat. The investigations were formally launched in 1982. Sea bed analysis and studies for preparation of feasibility report were of highly specialized and complex nature without precedence in the country. More than 12 specialized organizations of the Government of India and Government of Gujarat were involved in the field investigations. The techno-economic feasibility study was completed in a very scientific and systematic manner and the feasibility report submitted in 1988.

The proposed tidal power scheme envisaged a 900 MW project, biggest in the world, located in the Hansthal Creek, 25 km from Kandla Port in District Kachchh of Gujarat. Its main features were as follows:

The main tidal rockfill barrage of 3.25 km length was proposed to be constructed across the Hansthal Creek which will accommodate the power house, sluice gates and navigational lock. It envisaged installation of 900 MW capacity, comprising 36 geared bulb type turbo-generator units of 25 MW each, and 48 sluice gates, each of 10 M ×12 M. size, generating 1690 GW of energy annually (http://www.powertoday.co.in/fut4.html). Unfortunately, execution of this project has not been taken up so far because of unknown reasons.

In January 2011, Gujarat announced plans to install Asia's first commercial-scale tidal current power plant; the state government approved the construction of a 50 MW project in the Gulf of Kutch.

(b) *Durgaduani Creek* : The country's first tidal power generation project is coming up at Durgaduani Creek of the Sundarbans. The 3.75 MW capacity project is a technology demonstration project and will span over an area of 4.5 sq. km (2008 data).

### *2.7 Economics of Tidal Power*

Tidal power is characterized by high capital cost per MW of installed capacity, long construction times, no fuel cost, low running cost, and long lifetime with little maintenance, where annual operation and maintenance costs are typically less than 0.5% of initial capital cost of the scheme (http://geda.org.in/other_sources/other_re_ sources.html). Operation, however, is intermittent with a consequent low load factor of about 35%. There does not appear to be any significant economy of scale. Tidal barrage studies in UK with capacities from 30 MW to 8.64 GW yield similar energy costs. Possible consumption of power locally and shorter construction times for small schemes may make them more economic than the larger schemes. The high capital costs and long construction times of large tidal barrages make tidal energy particularly sensitive to the discount rate on the capital employed. Studies on the Severn Barrage show an almost linear relationship between the discount rate and cost of electricity generation in the scheme.

No energy benefits should be identified and taken into account in assessing viability of potential schemes.

### 2.8 Conclusions: Tidal Power

Tidal power generators are significant in their scale of engineering and are feasible for barrages in water depths up to 35 m. The Caisson method of construction is generally favoured, and suitable axial flow turbines of bulb or rim-generator type are proven and are commercially available. In operation, ebb generation is generally preferred while flood pumping can be used in addition, to increase and retime output. Output can generally be injected into strong transmission networks without retiming by use of pumped storage.

Regarding economics, there is no clear economy of scale; promising schemes which vary from 10 MW to 50 GW have been identified, but cost of electricity is sensitive to the discount rate on account of the technology being capital intensive. Positive environmental benefits include savings in emissions from fossil fired generation, but specific site environmental assessment is recommended for each barrage to clarify effects and establish acceptability. No insurmountable barriers to the technology have been identified to date.

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