Green and Sustainable Technologies: 2 Credits

Tidal Energy

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What we have discussed so far?

- Introduction to sustainability
- Sustainable Development Goals: A Brief Introduction
- The Blue-Green Economic Policy: The Creator of New Prospects in the Economy
- What is green technology?
- Importance of green technology
- Evolution of green technology
- Emerging green technologies
- Why is Green Technology Necessary?
- Principles of Green Engineering and principles of green chemistry
- Introduction to the concept of energy, Types and forms of energy, Energy sources, flow, Power, Energy losses and efficiency, Energy demand, Rising of renewables
- Introduction to renewable energy
- **Solar energy**
- **Wind Energy**

Today's Outline

Describe some devices for extracting power from tidal currents.

- Explain the theory of extracting power from the rise and fall (range) of tides, and why this renewable energy source has not been very widely exploited to date.

Wave, Tidal, and Ocean Thermal Power Resources

- Tremendous amounts of energy are available in oceans and seas due to waves and tides, which are mechanical form of energies as they are related to the kinetic and potential energy of the ocean water.
- Oceans also have thermal energy due to solar heating of ocean water.
- Ocean waves are ubiquitous and are caused by the interaction of the wind with the water surface.
- The amount of power in waves worldwide is enormous—probably greater than for freshwater hydro, but very little by way of wave power devices have been installed to date because the technology is not nearly as mature as for conventional freshwater hydro.

- OTEC is in even greater abundance worldwide but has been even less installed to date for much the same reason.
- The only one of the three alternatives to freshwater hydro that has a nonnegligible amount installed (at just a single power plant in France) is tidal power.
- The conventional wisdom on tidal power is that it suffers from having a very limited number of locations where it is practical and that the total amount of additional power worldwide that could practically be exploited is relatively small.

- Tidal power is the power inherent in tides at sea or oceans, that is the power of motion of water actuated by tides.
- Tides are defined as the increase and decrease in water levels due to the motion of water from one place to the other.
- This motion of water is actuated by large amounts of energy due to the movement of the Sun, Moon and Earth relative to each other and also to their rotational movement.
- Thus there is a renewable source of energy in the tidal motion of water at seas and oceans.
- This source of energy could be used to generate other types of energy that could be useful in industrial applications.

- The generation of electricity using tidal power is basically the transformation of tidal power
- found in tidal motion of water in seas and oceans into electrical energy.
- This is done using a very basic idea involving the use of a barrage or small dam built at the entrance of a bay where tides are known to reach very high levels of variation.
- This barrage will trap tidal water behind it creating a difference in water level, which will in turn create potential energy.
- This potential energy will then be used in creating kinetic energy as doors in the barrage are opened and the water rush from the high level to the lower level.
- This kinetic energy will be converted into rotational kinetic energy that will rotate turbines giving electrical energy.

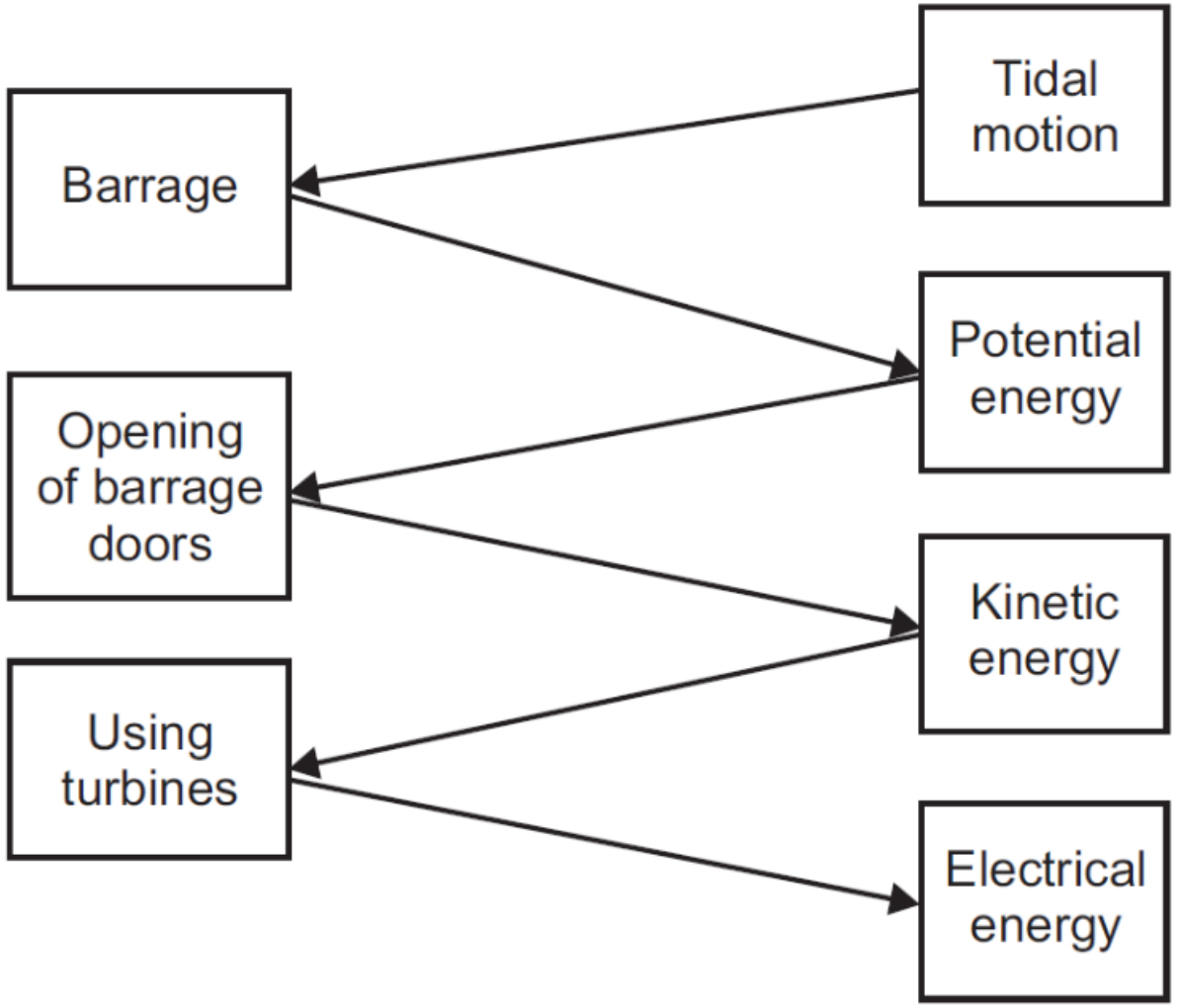

Fig. 1 A diagram showing transformation of tidal energy to electric energy

- Tidal energy offers an immense and reliable source of energy.
- The total energy flux of the tides is about 3 TW, however only a small fraction of this
- potential would be harnessed on the fore-seeable future.
- This is due to the fact that the energy is spread over a wide area.
- Tidal generation has a significant advantage over many other forms of renewable generation as it is almost perfectly predicted over long time horizons.
- Therefore, incorporating tidal generation into the system should be less challenging than other forms of renewable generation which are highly unpredictable.

- Harnessing tidal energy from the rise and fall of the tides has been exploited up to a commercial scale using tidal barrage systems.
- On the other hand, great efforts to exploit the kinetic energy from tidal currents have been directed.
- However, tidal current industry can benefit from the advances in technology and engineering resulted from the wind industry.

Physical concepts of the tidal phenomena

Tidal movements in seas are due to the increase of water levels at certain areas in the globe and the decrease of water levels at other areas.

This is basically due to two factors:

1. The gravitational forces between the Sun, Moon and Earth.

2. The rotation of the Moon and Earth.

- As there are gravitational forces between the Moon and the Earth, seas or oceans water is pulled away from Earth toward the Moon at the area where the Moon and the Earth are in front of each other.
- At the opposite side of the Earth the water is being pushed away from the Earth due to centrifugal forces.
- Thus as shown in Fig. 10.2 there are two areas where the water levels are high and other areas where the water level is low.
- Thus, the tidal motion of water is created.
- This is called the lunar tide.
- The same concepts that apply for the
- Moon apply for the Sun, yet, the Sun has a smaller effect on the water levels but when that can only contribute or lessen the effect of the Moon gravitational power.
- This is described by ‘spring tides’ where the lunar tide and solar tide are aligned and contribute to each other and by ‘neap tides’ where the lunar and solar tides are at right angles of each other and lessen each other.

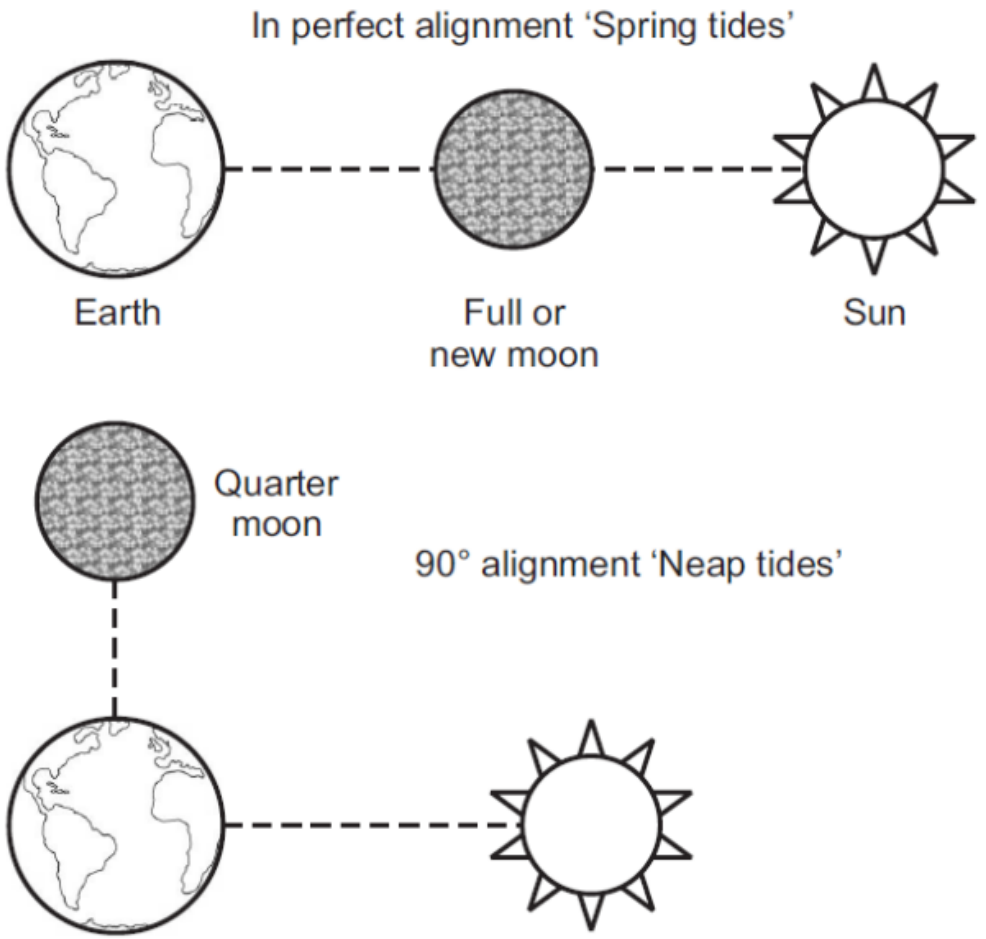

Fig. 2 Alignment of the Moon and Sun on tides

Principles of tidal power generation systems

In very simple terms a barrage is built at the entrance of a gulf and the water levels vary on both sides of the small dam.

Passages are made inside the dam and water flows through these passages and turbines rotate due to this flow of water under head of water.

Thus, electricity is created using the turbine

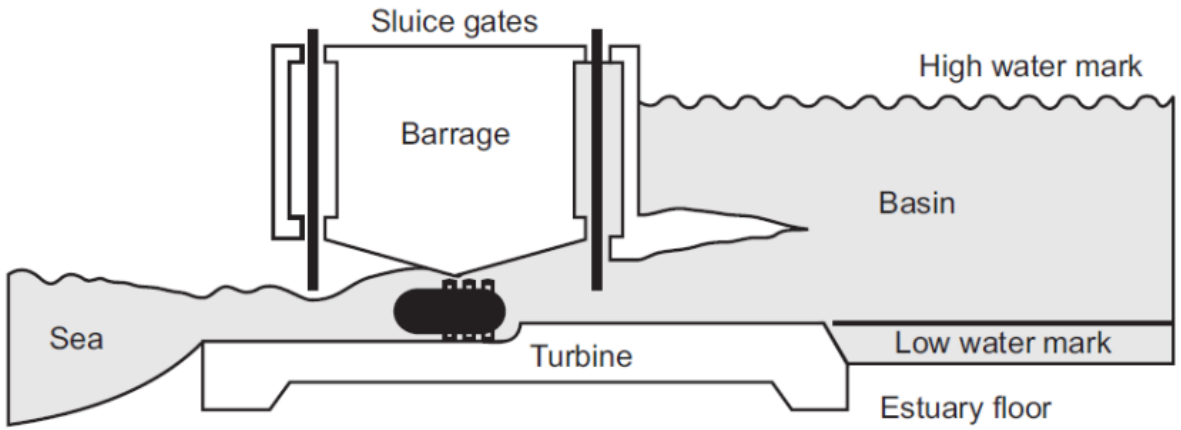

Fig. 3 General scheme of the tidal power station

Semidiurnal tides with monthly variation

- This type of tide has a period of 12 h 25 min, due to the Earth's rotation relative to both Sun and Moon, consequently, the tidal phenomenon occurs twice every 24 h 50 min 28s, so each landmass is exposed to two high tides and two low tides during each period of rotation.
- The amplitude of the tide varies according to the lunar month, with the higher tidal range at full
- Moon and new Moon, when Sun and Moon are aligned.
- Neap tides occur during half-Moon as the resultant gravitational pull is minimum.
- One of the tides has a greater range than the other, having a higher high and a lower low, therefore, a greater tidal flow while water is coming in and going out during the period between high and low levels.
- The tidal output peaks and troughs four times a day as the tide comes in and out twice daily.

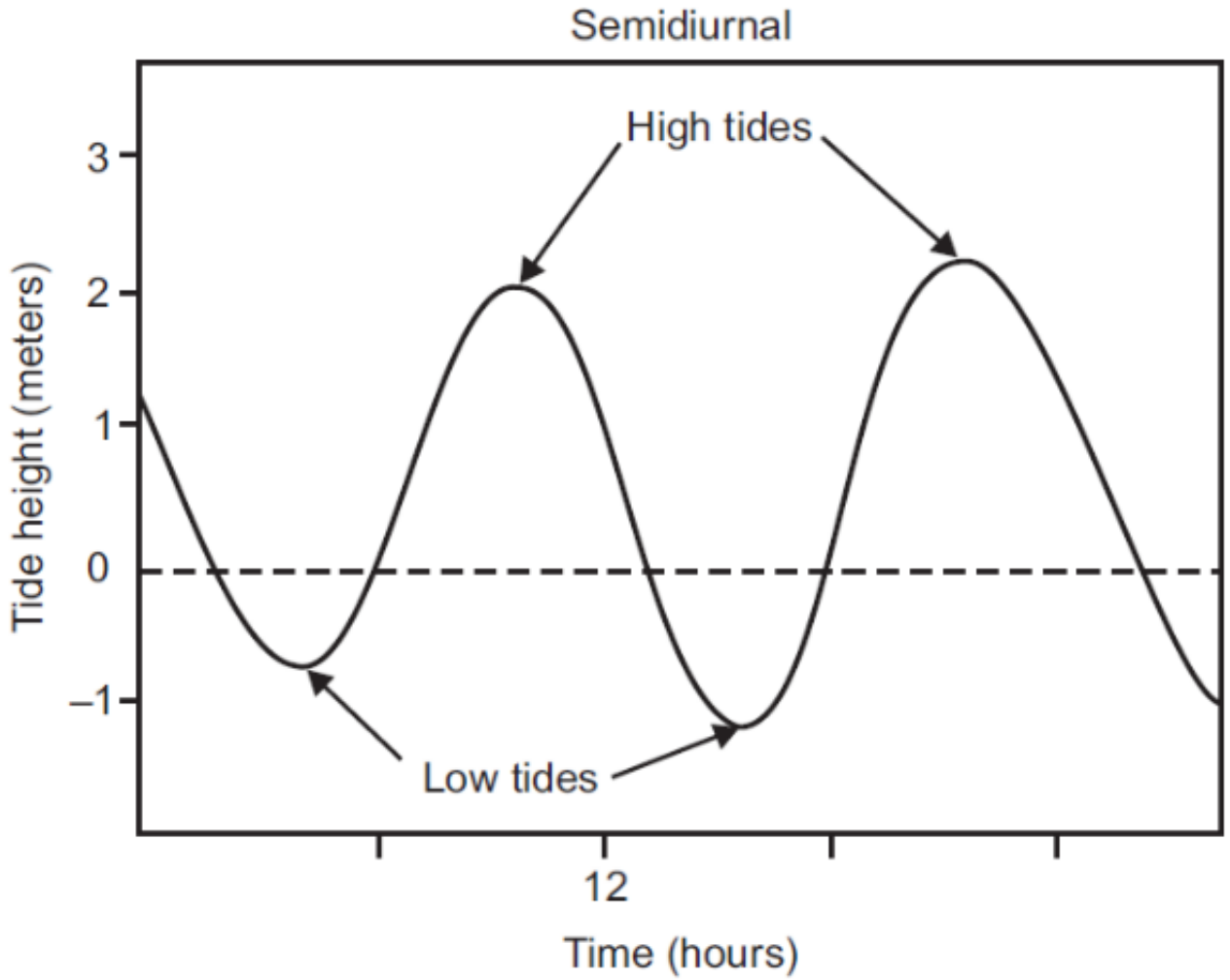

Fig. 4 Semidiurnal tide

Diurnal tides with monthly variation

- This type of tide is found in China Sea and Tahiti.
- In this case, the tidal period is 24 hr 50 min 28s, a full revolution of the Moon around the Earth.
- During each Earth rotation, a point of the Earth's surface will pass through different parts
- of the equilibrium tide envelope and therefore experience a diurnal variation in tide levels.

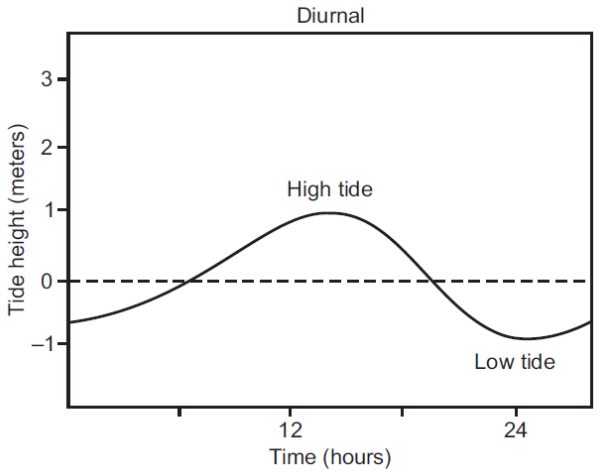

Fig. 5 Diurnal tides

Mixed tides

This type of tides combines the characteristics of diurnal and semidiurnal tides.

Moreover, they can also display monthly and bimonthly variations.

They are found in the Mediterranean Sea and at Saigon.

There are several periodic phenomena that affect on tidal behaviour.

1. A 14-day cycle, due to the interaction of the gravitational field of the Sun and Moon. As a result of the Moon's elliptical orbit the cycle is slightly modified, so successive spring-neap tides can vary in amplitude by about 15%.

2. A half-year cycle, as a result of the Moon orbit inclination gives place to a 178 days period between the highest spring tides, which take place in March and September.

3. The Saros, period of 223 synodic periods equivalent to 18 years and 10 days, is the time required by the Earth, Sun and Moon to return to the same relative positions.

- Tidal currents occur in coastal areas and in places where the sea-bed forces the water through relatively narrow boundaries.
- Thus both high tidal ranges and narrow channels are generally required to cause significant tidal stream currents.
- The range of a spring tide is commonly about twice the neap tide range.
- The common tidal range is about 50 centimeters in the open ocean.
- However, the tidal amplitude can be increased by several local effects such as shelving, funneling, reflection and resonance.
- The shelving effect consists of increasing the deep water tidal wave height as the wave slows down when entering shallow water areas.

- The tidal amplitude can be further increased due to funnelling effect, which occurs when the tidal bulge progresses into a narrowing estuary.
- Moreover, tidal wave can also be reinforced by reflections of the waves by the coastline.
- At some sites, the tidal flow can be heightened to more than 10 meters by resonance effects, i.e., Bay of Fundy, in Canada, where the greatest tides in the world can be found, and the Severn Estuary in England.
- The resonance effect takes place when the tide at the mouth of the estuary can resonate with
- the natural frequency of tidal propagation up the estuary.

- Tidal currents can flow in two directions; the current moving in the direction of the coast is known as flood current and the current receding from the coast is known as ebb current.
- The current speed varies from zero to a maximum.
- The zero current speed occurs between the ebb and the flood current, slack period; while the maximum speed is reached halfway between the slack periods.
- All tidal variations rise and fall and flood and ebb current can be utilised to generate electricity.
- The generation of electrical power from ocean tides is very similar to hydroelectric generation.

Components of a tidal power system

- The energy extracted from the tides can be obtained from both, the vertical water movements associated with the rise and fall of the tides, potential energy or the kinetic power, which is the result of the roughly horizontal water motions termed as tidal currents.
- For these reason, tidal power facilities can be categorised into two main types:
  - tidal barrages and
  - tidal current turbines.

1. Single basin tidal barrage

- Single basin tidal barrage consists of one basin and requires a barrage across an estuary or a bay
- There are three main operation patterns in which power can be generated within a single basin: ebb generation, flood generation and two-way generation.

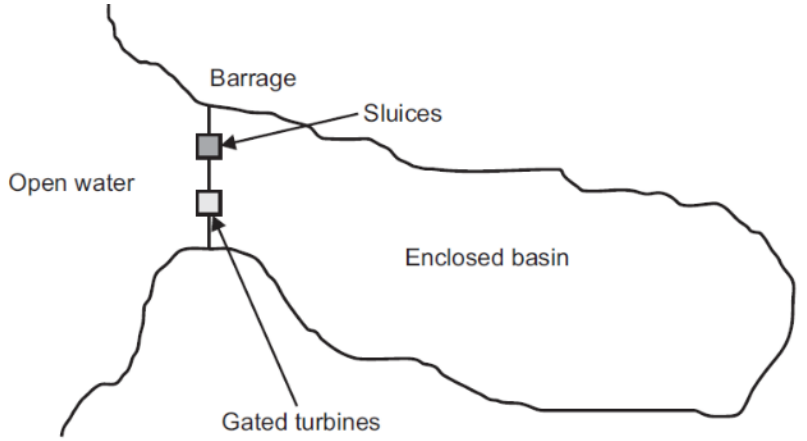

Fig. 6 Single basin tidal barrage

2. Double basin tidal barrage

- This system requires the construction of two barrages, the main one and the inner one, giving place to two basins.
- The main basin is essentially the same as ebb generation in a single-basin system.
- The only difference is that in this case, part of the energy produced by it is used to pump water into the second basin.

Types of turbines

- They are the components responsible for converting potential energy into kinetic energy.
- They are located in the passage ways that the water flows through when gates of barrage are opened.
- Turbines are one of the main elements for electricity generation in tidal barrages.
- The turbine choice will determined the operation conditions and the environmental impact, for these reason several aspects such as, head variability, flow rate, requirements for pumping or continuous operation, requirements for two-way generation operation, start-stop frequency, etc., have to be considered.
- It is worth mentioning that due to the development in turbines design, routine repair is carried out with a greater ease, thus, maintenance is no longer consider a development issue.
- Nowadays, there are several types of turbines available; the most commonly used are bulb, rim and tubular turbines.

Bulb turbines

- Bulb turbines are a type of hydro turbine, whose name comes from the shape of the upstream watertight casing which contains the generator located on the horizontal axis and is mounted inside the water passageway as an integral unit with the turbine.
- This installation can offer significant reductions in size, cost, and civil work as there is a low need for excavation and what is more, the draft tube improves the hydraulic behavior of the bulb unit.

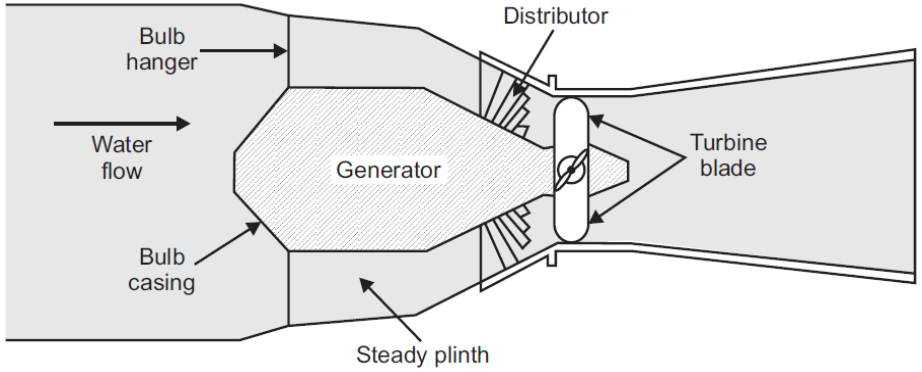

Fig. 7 A Bulb turbine

- During its operation water floods around the turbine, its maintenance is difficult, as while it is carried out, water has to be prevented from flowing through the turbine.
- This means that when inevitable maintenance of the turbine or/and the generator is needed, it has to be lifted off the water, and consequently, the turbine stops producing power for the duration of the process.

Rim turbine

- Rim turbines generator is separate from the turbine itself; it is mounted on the barrage and is connected through a shaft that moves with the turbine; consequently, only the turbine is in water flow.
- Moreover, the rotor is protected from ingress of sea water by especially designed water seals.
- Concerning maintenance, it is necessary to remove them when turbine maintenance is required, although the generator can be accessed when water inlet gate is closed and water drains off.
- As a result, the generator maintenance problem in bulb turbines is solved.

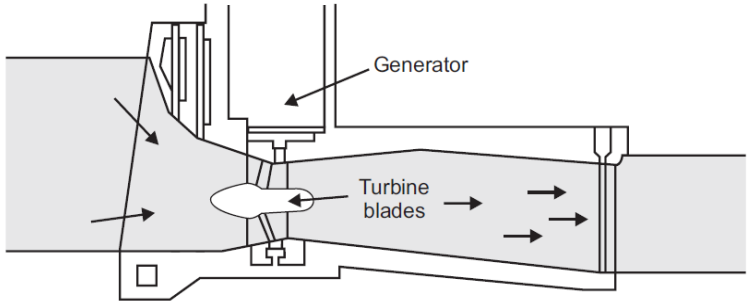

Fig. 8 Rim turbines generator

Tubular turbines

- In tubular turbines generator is mounted on the top of the barrage at a 45 degree angle with the turbine, and the blades are connected to a long shaft.

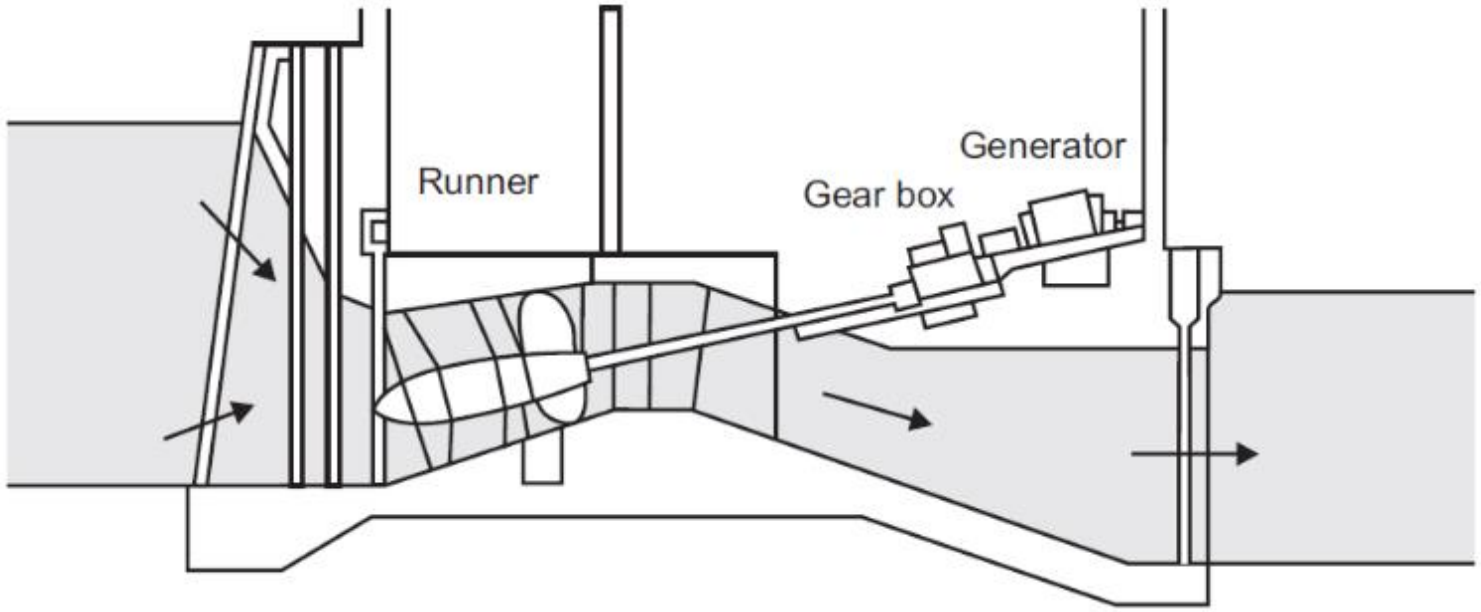

Fig. 9 Tabular turbines generator

Tidal current turbines

- Tidal current turbines extract the kinetic energy from the moving unconstrained tidal streams to generate electricity. Currents have the same periodicity as vertical oscillations, being thus predictable, although they tend to follow an elliptical path.
- In the simplest form a tidal current turbine is constituted by a number of blades mounted on a hub, a gearbox and a generator.
- The hydrodynamic effect of the water when flowing through the blades causes the rotor to rotate, thus turning the generator to which the rotor is connected through the gearbox.
- The gearbox is used to transform the rotational speed of the rotor shaft to the desire input of the generator.
- The electricity produced is transmitted to land through cable.
- As previously commented, tidal current turbines extract the kinetic energy from the currents to generate electricity.
- Currently, there are mainly two types of turbines, horizontal axis and vertical axis tidal current turbines.

Reciprocating devices

- Reciprocating devices have blades called hydrofoils – shaped like airplane wings – that move up and down as the tidal stream flows on either side of the blade.
- The up and down movement of the hydrofoils is subsequently converted into the rotation to drive a rotating shaft, or connected to pistons to support a hydraulic system for power generation.
- The advantage of reciprocating devices is that the length of the blade is not constrained by water depth, however it also requires complex control systems to pitch the blades correctly.

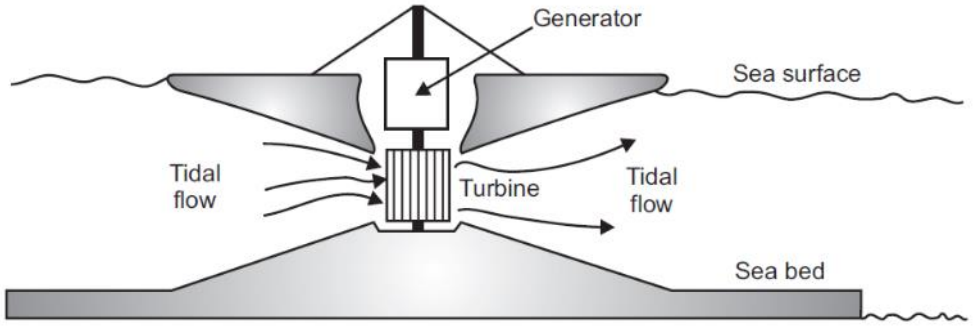

Fig. 10 Tidal current power device

Tidal current

- Tidal current technology is stills in its infancy.
- However, recent developments open up prospects for commercial deployment of some schemes in the near future.
- Up to the moment, some down-scale models and full-scale prototypes have been developed, while some are currently in operation others are about to be installed, mainly in Europe.

Barriers and drivers in tidal energy

1. The greatest barrier to tidal range technology advances are the relatively **high upfront costs** related to the developments of the dykes or embankments, and the ecological implications of enclosures or impoundments.

2. Due to tidal cycles and turbine efficiency, the load factor of a conventional tidal barrage

is around 25%, which leads to high cost of energy.

- Improvement in turbine efficiency, in particular innovative reversible turbines for ebb and flood generation, should provide a significant increase in energy yield.

- One important new avenue is the use of tidal range applications to promote ecological improvement.
- In all these solutions (e.g., in the case of the Sihwa barrage or potentially in case of the Grevelingen lake in the Netherlands), the installation of tidal range technology leads to several important societal benefits besides renewable energy.
  - flood defense,
  - improved environmental and ecological water quality, and
  - fisheries and
  - tourism functions.
- An important new application for tidal range energy under development is one that is focused on harvesting energy from low head tidal differences of less than 2 meters (m).

- For tidal stream technologies, continued support for demonstration and grid connection of larger-scale arrays will be critical.
- With these experiences, the materials, operation and maintenance costs can be improved.
- Furthermore, high installation costs of both tidal range and tidal current solutions need to be overcome through capital investments, aiding commercialization, feed-in tariffs or investment mechanisms in innovation.
- The simultaneous research and development of new infrastructure of flood defences, coastal restructuring, bridge and road construction, also offer opportunities to advance tidal energy technologies.

Technology barriers

- Technological challenge for the tidal range is to increase the efficiency of the turbines.
- For tidal current technologies, the basic technologies exist but technical challenges continue to arise due to
  - insufficient experience with materials,
  - working and fixing structures in a harsh environment, demonstration,
  - a lack of information and knowledge regarding performance, lifespan, operation, and maintenance of technologies and power plants.
- For tidal current technology to become a real alternative to conventional energy sources, increased attention needs to be paid to technical risks in design, construction, installation, and operation.
- Moreover, imparting knowledge and experience from other industry sectors, such as offshore oil and gas installations and offshore wind farms, including risk assessments, environmental impact assessments, and engineering standards, is of great importance.

- This is not an easy process as much of this information is proprietary and of competitive advantage to firms.
- Furthermore, oil and gas technologies are often not the same as technologies for renewable projects (e.g., high spec, high cost, one-off uses vs. lower-cost, mass-produced)
- More extensive research on new materials and methodologies, and rigorous testing on new sub-components and complete functional prototypes are still necessary to establish these new technologies.
- For tidal current technologies, costs of fixtures to the sea-bed, and maintenance and installation costs need to be brought down.
- Furthermore, more experience in deploying arrays is required.

Tidal barriers:

- Tidal barriers are large and expensive structures that may require years to construct.
- No power can be produced, and hence no income generated, until the last section of the barrier is complete.
- Difficulties in finance may lead to lack of environmental care.
- Although the installation at La Rance now features a flourishing natural ecosystem, it is noticeably different from that which was there before the dam, and took some years to establish itself.

Difference between tidal energy and wave energy

Tidal energy	*Wave energy*
Harnessed from the rise and fall of sea levels	Harnessed from waves moving along the surface of the ocean
Caused by the gravitational pull of the Moon and Sun on the Earth	Caused by wind
Intensity is affected by location and position of the Earth	Intensity is affected by wind strength Often referred to as wave power
Types of tidal energy include kinetic and potential energy	Types of wave energy include kinetic energy
Harnessed using barrages, dams, tidal fences and tidal turbines	Harnessed using offshore and onshore systems
More reliable since it is based on the gravitational pull of the Moon and Sun	Less reliable since it is based on the effect of the strength of the wind on the surface of the water
Discontinuous source of energy that is generated for about 6–12 h at a time	Continuous source of energy
Can disrupt migrating routes of birds and boating pathways and result in large amounts of fish kill	Effect on surrounding environments, ecosystems and communities are low
High construction costs but low maintenance costs	Extremely high start-up costs to design and develop the technology required

Advantages of tidal energy

1. It is an inexhaustible source of energy.

2. Tidal energy is environment-friendly energy and doesn't produce greenhouse gases.

3. As 71% of Earth's surface is covered by water, there is scope to generate this energy on large scale.

4. We can predict the rise and fall of tides as they follow a cyclic fashion.

5. The efficiency of tidal power is far greater as compared to coal, solar, or wind energy. Its efficiency is around 80%.

6. Although the cost of construction of tidal power is high maintenance costs are relatively low.

7. Tidal energy doesn't require any kind of fuel to run.

8. The life of tidal energy pobutwer plant is very long.

9. The energy density of tidal energy is relatively higher than other renewable energy sources.

Disadvantages of tidal energy

1. The cost of construction of tidal power plants is high.

2. There are very few ideal locations for the construction of plants and they too are localized to coastal regions only.

3. The intensity of sea waves is unpredictable and there can be damage to power generation units.

4. Influences aquatic life adversely and can disrupt migration of fish.

5. The actual generation is for a short period of time. The tides only happen twice a day so electricity can be produced only for that time.

6. Frozen sea, low or weak tides, straight shorelines, low tidal rise or fall are some of the obstructions.

7. This technology is still not cost-effective and more technological advancements are required to make it commercially viable.

8. Usually, the places where tidal energy is produced are far away from the places where it is consumed. This transmission is expensive and difficult.

- Tidal energy is thus a clean source of energy and doesn’t require much land or other resources as in harnessing energy from other sources.
- However, the energy generated is not much as high and low tides occur only twice a day and continuous energy production is not possible.

References

S. C. Bhatia, R. K. Gupta. 2018. Tidal Energy, Chapter 11 in: Textbook of Renewable Energy. Woodhead Publishing India Pvt Ltd. New Delhi.