BMM4753 RENEWABLE ENERGY RESOURCES

Chapter 7. Ocean Tidal Energy

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Chapter 7. Ocean Tidal Energy

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7.1 Introduction

Ocean covers approximately 70% of earth's surface and represents a huge reservoir of various useful and renewable energy resources. World's total estimated ocean energy reserves are about 130 X 10^6 MW but only a small fraction can be recovered economically. Present use is negligible and interest in ocean energy has been revived after the energy crisis of 1973 and likely to gain a significant importance during the coming decades as fossil fuel sources is rapidly depleting combined with the adverse environmental impacts. The various ocean energy conversion technologies are presently in infant stage and the cost is prohibitively high including:-

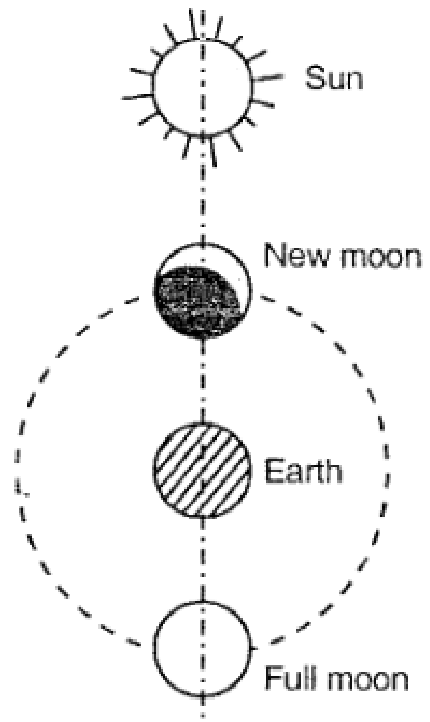
- Ocean Tidal Energy Conversion
- Ocean Wave Energy Conversion
- Ocean Thermal Energy Conversion (OTEC)

7.2 Characteristics of tidal energy

- All forms of energy available on earth are derived from solar energy, with the exception of nuclear, geothermal and tidal energy.
- Wind, ocean waves, and rivers are driven by the energy from the sun.
- Coal, oil, gas, wood and grasses are formed by solar energy, which splits carbon dioxide with water to produce cellulose which has either been fossilized or converted to starch and sugar to produce biomass.
- The tides are caused by the combined attraction of sun and moon on the waters of the revolving globe.
- The effect of the moon is about 2.6 times more than that of the sun, influencing the tides of the oceans.
- Tide is a periodic rise and fall of the water level of the ocean, twice during a lunar day i.e. 24 hours 50 minutes in which the water in oceans and seas rises and falls.
- The excess of 50 minutes over the solar day results in the maximum water level, occurring at different times on different days.

7.2 Characteristics of tidal energy

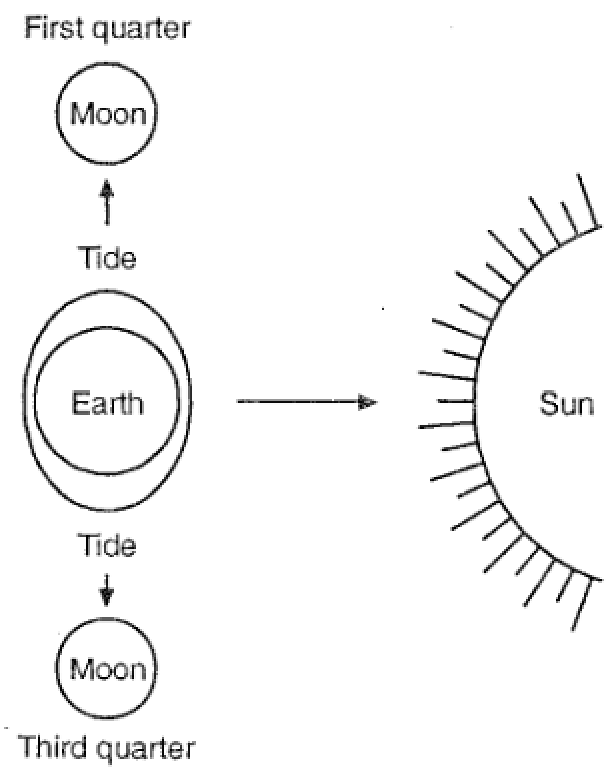
- The amplitude of water level variations at different points on the earth depends on the latitude and the nature of the shore.
- The rotation of the earth causes two high tides and two low tides to occur daily at any place.
- The revolution of the moon around the earth increases the time interval between two successive high tides from 12 hours to about 12 hours and 25 minutes.
- As the moon revolution takes about 28 days, the three bodies, i.e. the sun, the moon and the earth are in alignment every two weeks at new and full moon.



Sun and Moon Combination Act To Create Spring Tides

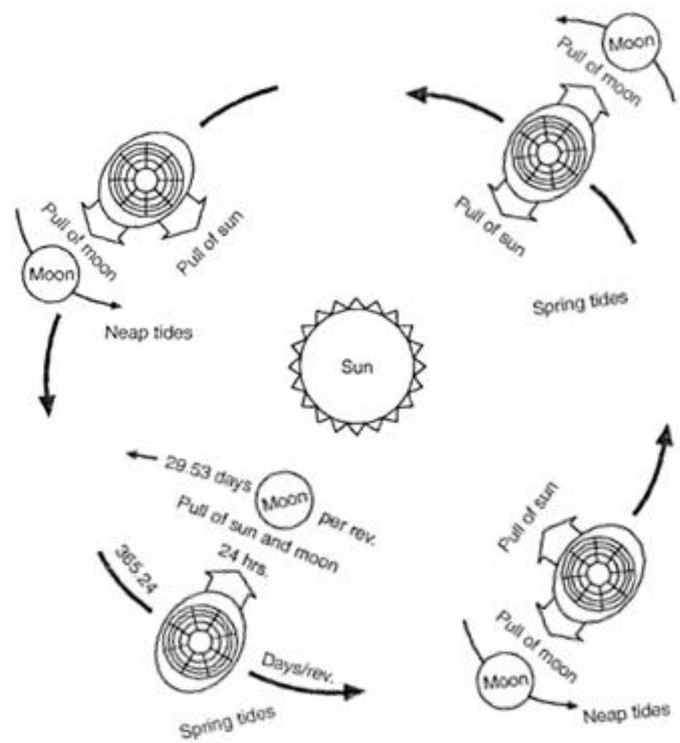
7.2 Characteristics of tidal energy

- During these periods the sun and moon act in combination to produce tides of maximum range as shown.
- The solar pull comes in line with the lunar pull at 'New Moon' and 'Full Moon', causing greater flow and ebb, known as spring tides.
- When the two pulls act at right angles to each other, as at waxing and waning 'Half Moons', i.e. in first and third quarters, we get low tides called 'Neap Tides' as shown.



7.2 Characteristics of tidal energy

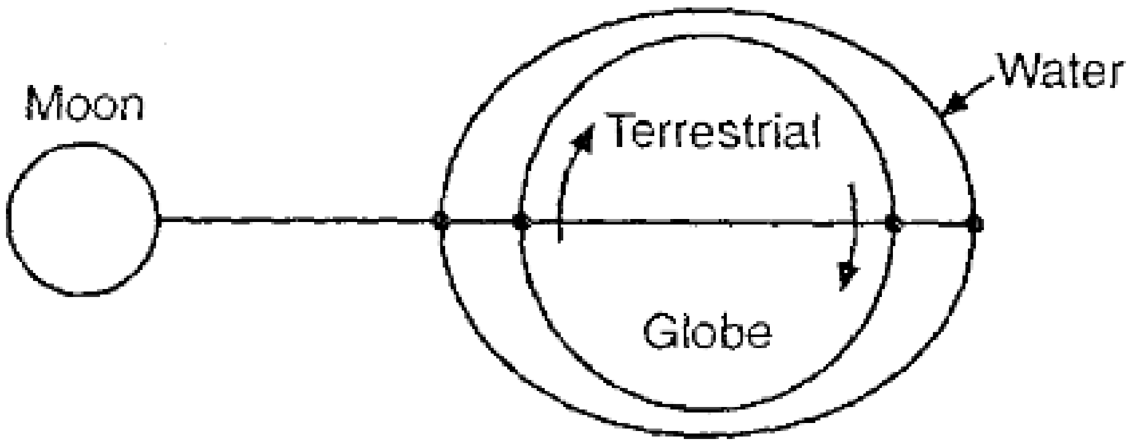
- The spring tide is particularly great when the moon is 'New' and 'Full' at which time it is at the closest point of its orbit to the earth.
- The revolution of the earth and the moon together around the sun gives rise to further variation, and due to this effect the highest spring tide occurs at the equinoxes in March and September.



Origin of tides

7.2 Characteristics of tidal energy

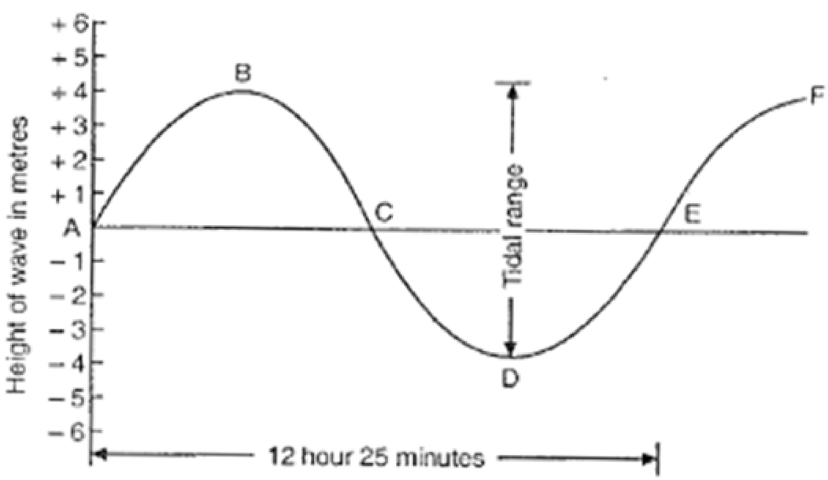
- A high tide is experienced at a point which is directly under the moon. At the same time, at a diametrically opposite point on the earth's surface, there also occurs a high tide due to dynamic balancing of the ocean water over the globe.
- In the course of the earth's rotation the water bulges out.



Distribution of water over the earth's surface under the effect of the moon

7.2 Characteristics of tidal energy

Tidal range is the difference in water levels between two consecutive high tides and low tides. The rise and fall of water level in the sea during tides can be represented by a sine curve. Point B, a position of high tide, while the point D represents a position of low tide.

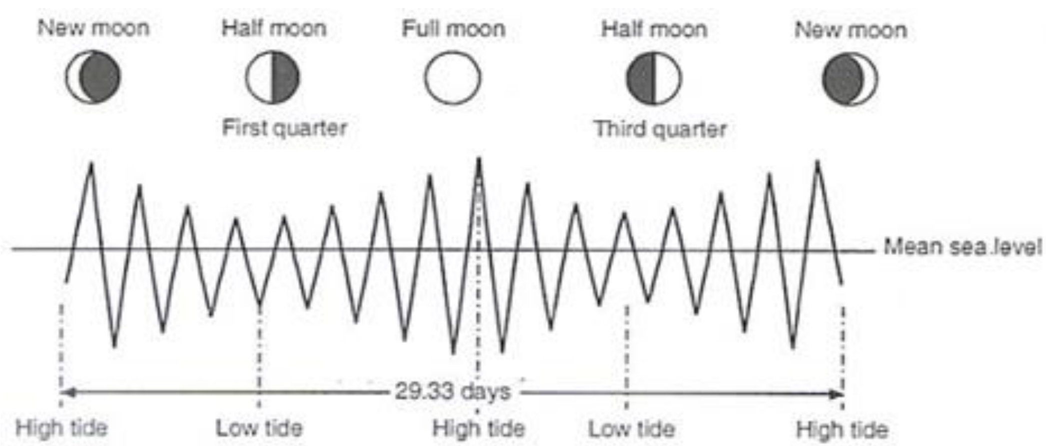


Tidal range

One tidal day is of 24 hours and 50 minutes and there are two tidal cycles in one tidal day. The normal tide is a semi-diurnal tide with a period of 12 hours and 25 minutes. Diurnal means daily, i.e. activities of tide pattern during 24 hours. Diurnal tides indicate two high and two low tides created by moon during one rotation of the earth on its axis. The daily tidal cycle follows a sinusoidal pattern.

7.3 Tidal Energy Conversion – Estimate

Amplitude of tidal range reduces steadily from spring tide to neap tide, and then increases with the same pattern to the next spring tides. This monthly cycle occurs due to one revolution of the moon around the earth. Both the tide cycles, namely the daily and the monthly cycles at a particular location repeat in a most orderly fashion and are predictable. The tides are caused by cosmic phenomena, and are not affected by weather conditions and yearly rains.



Water level variation caused by tides during one lunar month.

Both the periodicity and predictability of tidal action are important characteristics which favor strongly the utilization of this phenomenon as an energy source.

7.3 Tidal Energy Conversion – Estimate

Tides at any location repeat themselves almost identically in a cycle of 19 years. Within any one year interval, the differences are small, and the available energy is practically the same from year to year. Precisely for the semi-diurnal tides, there is a relation between the tidal range and the hours of the high and low tides. Thus, at a particular location, the tidal range at a given time during the day shall always be within limits of the known maximum value. The tide range varies and depends upon the land situation against the sea.

- On open, exposed head lands, tides are moderate which may range from 1 to 2 m.
- In a gulf, bay or creek, tides are greatly amplified, in certain cases several times than those occurring at a nearby open coast. The amplification is maximum if the bay is funnel shaped.

7.3 Tidal Energy Conversion – Barrage and basin

In the tidal power scheme, a barrage is used to create the water head considering the variation of tidal height in the basin. The barrage is used to impound water during rising tide in one or more basins, which is then released through hydraulic turbines installed in the barrage during the period the tide recedes. Thus, the potential energy of water is converted into electrical energy.

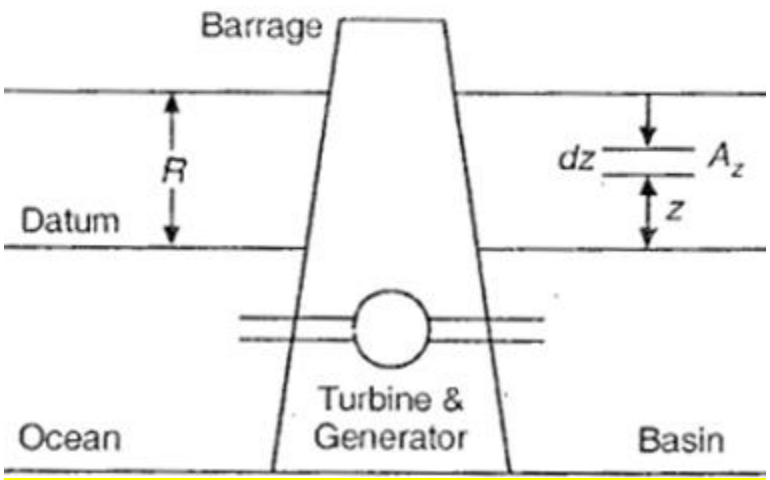
For optimal output of tidal power plant, an estuary or creek is the best choice for constructing the barrage.

- It provides high tidal range besides large storage of water.
- By using a reversible turbine, electric power can be generated during the rising tide, when the basin is filled, and again during the falling tide when the basin is emptied.

7.3 Tidal Energy Conversion – Barrage and basin

Consider a basin of surface area A m^2 at the maximum basin level. Let R be the range of the tide and V the volume of water stored from the low level to high tide level. The volume of water contained in an elemental strip of thickness dz; at surface area of A_z, at a depth z above the low tide in the basin, $dV = A_z dz$.

Assume that the basin is empty with its water level, $z = 0$ and the ocean is at high tide level, $z = R$. By instantaneously filling the basin, the energy potential available is E_f



Ocean with single basin tidal project

7.3 Tidal Energy Conversion – Barrage and basin

Energy potential available is E_f,

$$\boldsymbol{E_f} = \rho . g \int_{z=0}^{z=R} z . A_z dz = A_z . \rho . g \int_{z=0}^{z=R} z . dz = \boldsymbol{A . \rho . g \frac{R^2}{2}}$$

where $\rho = \text{sea water density} \qquad = 1025 \text{ kg}/m^3$

$\qquad g \;= \text{gravity} \qquad\qquad\qquad = 9.81 \text{ m}/m^2$

The above equation provides energy conversion from a single basin type with single effect, i.e. either filling the basin or emptying the basin. The duration of time for single effect is 6 hours and 12.5 minutes which is equal to 22350 seconds.

7.3 Tidal Energy Conversion – Barrage and basin

The average theoretical power *P* generated by the water is *W* in watts during a semi-diurnal tide of 6 hours and 12.5 minutes (22350 seconds).

Average power during generated during one filling or emptying process ,

$$\boldsymbol{P} = \frac{E_f}{Time} = A\rho g \frac{R^2}{2} \times \frac{1}{Time} = \frac{1025 \times 9.81}{2 \times 22350} AR^2 = \mathbf{0.225}\ \boldsymbol{AR^2}\ \mathbf{W}$$

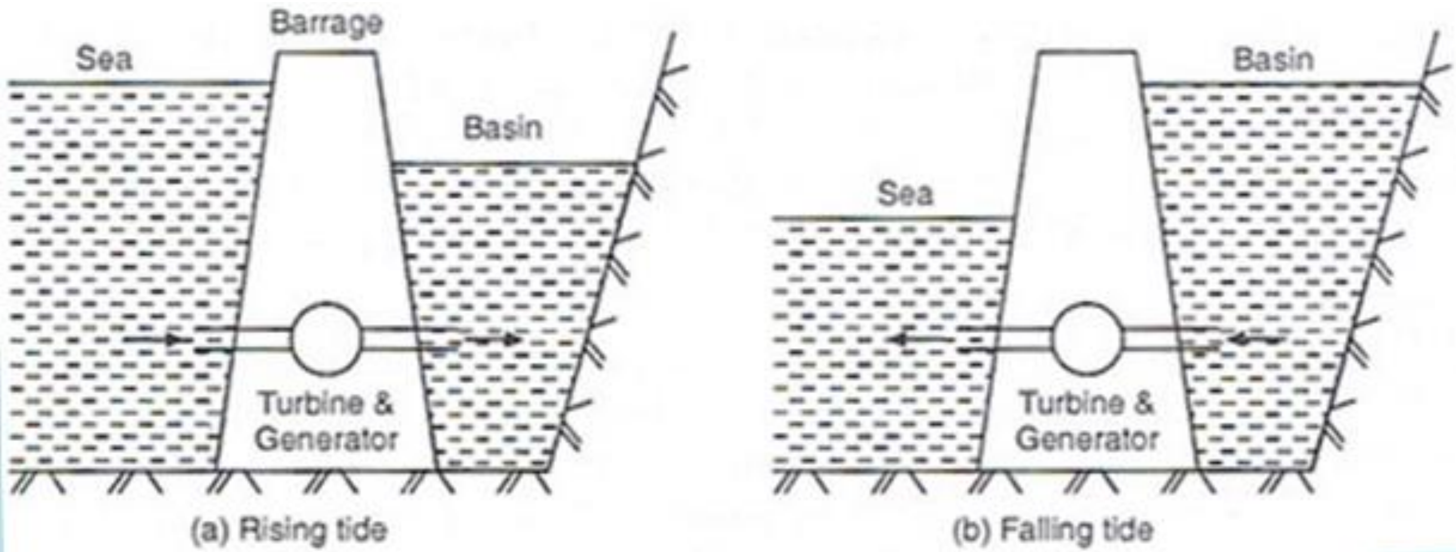
where, *A* = area of the basin in m^2

R = range of the tide in m

The average power is calculated based on average operating head of *R/2* for a limited period in a single basin emptying operation. There are friction losses, conversion efficiencies of turbine and generator that reduce the power output. Hence, that the optimal annual energy production is only 30% of the average theoretical power calculated above.

7.3 Tidal Energy Conversion – Double cycle system

In a double effect system as shown, the energy available in tide sea water is converted into electrical energy during flood tide (rising tide) when the basin is filled and also during the ebb tide (falling tide) when the basin is emptied.



Double Cycle System

7.3 Tidal Energy Conversion – Double cycle system

The flow of water through the turbine during rising and falling tides is in opposite directions. For this reason, a reversible water turbine is used, which acts as a turbine for either direction of flow.

- During rising tides, a large quantity of water flows into the basin through the turbine by opening the sluice gate. Filling of the basin continues along with the generation of electric power until the tide water levels of the sea and the basin become equal. At this position the sluice gate is closed.
- Subsequently, during falling the tide water from the basin flows into the sea through the turbine and electric power is generated. As the water level in the basin drops, a point is reached when the difference in water levels between the sea and the basin becomes too small to generate power. At this point of time the generating units are shut down.
- The basin is again filled during rising tide and the cycle repeats to convert tidal energy into electrical power.

7.3 Tidal Energy Conversion – Double cycle system

The average power generated during one filling of the basin, $P = 0.225\,AR^2$

During the emptying process of the basin, the same amount of power is generated. Thus, the energy potential available during the filling and emptying operations is given by

$$E_f + E_e = A\rho g\frac{R^2}{2} + A\rho g\frac{R^2}{2} = A\rho g R^2$$

The theoretical average power generated in a double effect, single-basin system is given by

$$P_f + P_e = 2 \times 0.225AR^2 = 0.450AR^2 \text{ W}$$

The double effect tidal plant generates double energy per tidal cycle, so it is 100% more efficient than the single effect plant.

7.3 Tidal Energy Conversion – Yearly generation

To harness tidal energy, for maximum efficiency a double cycle system is most suitable. In real sense the tidal energy is the potential energy of sea water. For filling the basin, sea water gains potential energy due to lunar gravitational pull; while for the emptying process, the basin water flows out due to gravity action of the earth. The energy available from a tidal plant depends on two factors, namely the tidal range and the volume of water accumulated in the basin.

- Tidal energy is the slowly-increasing hydro energy during filling of the basin, and after a period of nearly three hours it attains its peak value.
- When the tide recedes, water is allowed to flow from basin to sea; it is then slowly-decreasing hydro energy and attains its lowest value when the turbine stops after a period of three hours.

7.3 Tidal Energy Conversion – Yearly generation

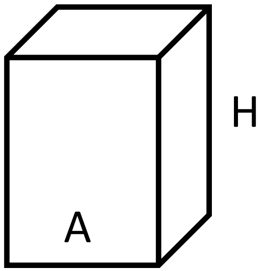
Thus, the energy available from a tidal plant can be calculated in a similar way as for an hydro-electric plant. Assuming the following:

H = tidal range, i.e. the difference between the maximum and minimum water levels in the basin, in m

A = mean base area of the basin, in m

V = volume of water that can be contained in the basin, in m

= AH



The average quantity of water Q in cubic meter per second that flows in or flows out from the basin. Therefore, $Q = \frac{AH}{t}$

where t is the total time in seconds required for filling or emptying the basin.

Theoretical work done by Q quantity of water falling through H' m is given by

$$W = \rho Q H' \text{ kg.m}$$

7.3 Tidal Energy Conversion – Yearly generation

Power generated at any point of time, $P = \frac{\rho Q H'}{75}\eta$ hp

where ρ = 1025 kg/m^3 for sea water, 1 hp = 75 kg-m/s, η = system efficiency

Hence, $P = \frac{\rho Q H'}{75}\eta \times 736$ W since 1 hp = 736 W

Total energy per tidal cycle = $\int_0^t P dt = \int_0^t \frac{\rho Q H'}{75}\eta \times 736\, dt$

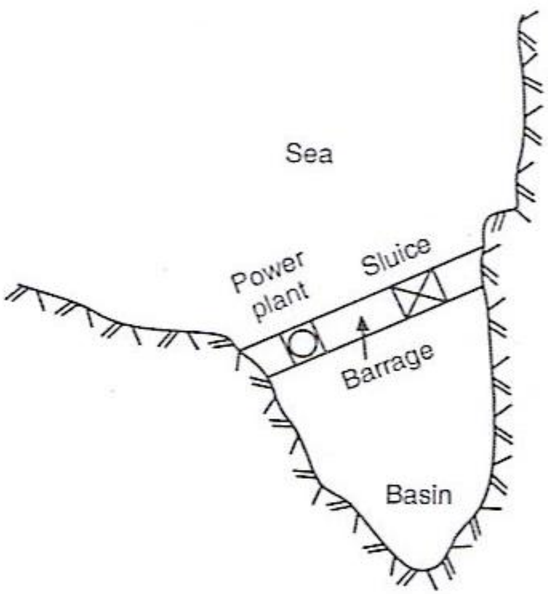
There are, on average, 705 tidal cycles in a year

Yearly power generation from a tidal project

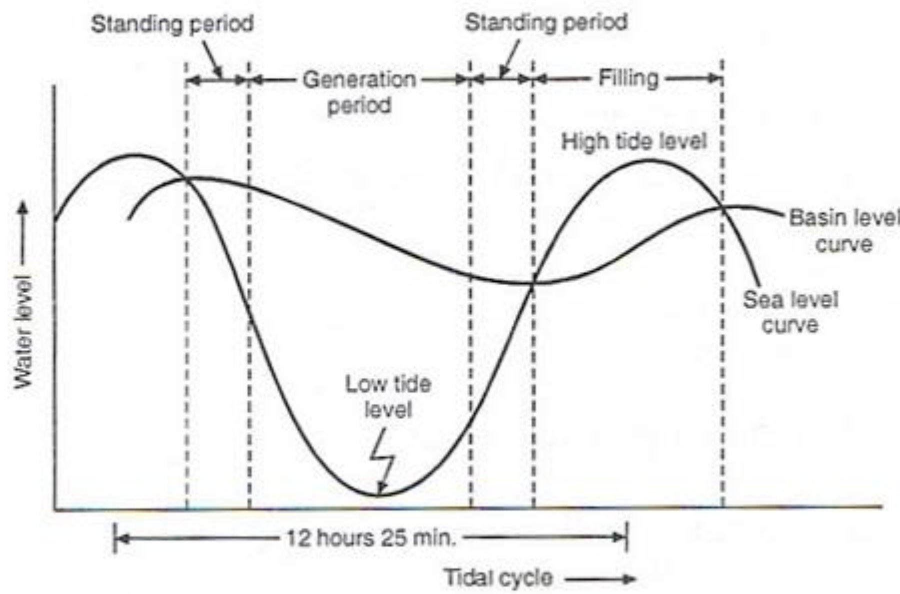
$$P_{year} = \int_0^t \frac{\rho Q H'}{75}\eta \times 736 \times 705\, dt = \mathbf{7.0914 \times 10^6 \eta \int_0^t Q H' dt} \text{ W}$$

7.4 Tidal Energy Power Plants

i. Single-basin single-effect plant is the oldest form of tidal power development and the basis of many tide mills. It is simply a barrage (dam or dyke) across an estuary or creek, whose principal elements are a powerhouse and a sluice.



Single-basin single-effect tidal plant.



Operating cycle of single-basin single-effect plant.

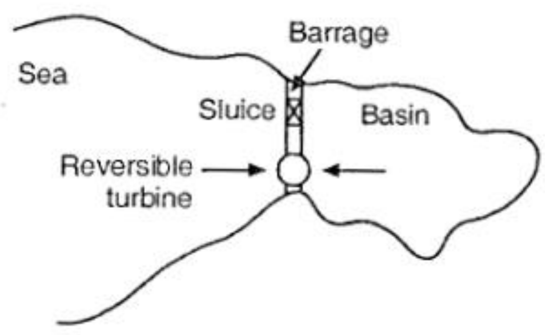
7.4 Tidal Energy Power Plants

i. Single-basin single-effect plant ...cont'd

- The basin is filled through the sluice by the rising tide. The water level in the basin reaches the highest level of the tide. It provides the water head of tidal range to the turbine. The sluice gate is closed.
- The turbine is started only when the water in the sea is at falling tide level. As the tide continues to fall a hydraulic head is formed at the barrage and at an appropriate time water is released from the basin through the generating unit installed in the powerhouse.
- Electric power generation continues until the head is reduced to the minimum turbine operating level. It normally occurs after the tide has reached its lowest point and has begun to rise again. At this stage the turbine water passage is closed and all discharge from the basin is stopped. When the rising tide reaches the basin level, the filling sluice is opened, refilling of the basin starts and the cycle is repeated.

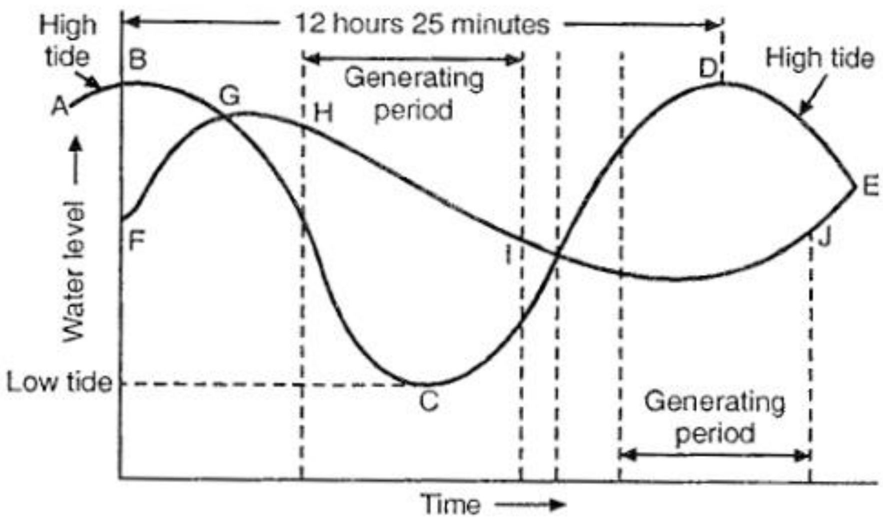
7.4 Tidal Energy Power Plants

ii. <u>Single-basin doule-effect plant</u> arrangement makes use of the combination of the ebb tide and the flood tide working, and power is generated both during emptying and filling of the basin. With a single barrage the water head which produces the energy operates from the sea towards the basin during the flood tide and from the basin towards the sea during the ebb tide.



Curve ABCDE shows the tide level in sea.
Curve FGHIJE shows the basin level.

(a) Single basin with reversible turbine



(b) single-basin double-effect power plant operating cycle.

7.4 Tidal Energy Power Plants

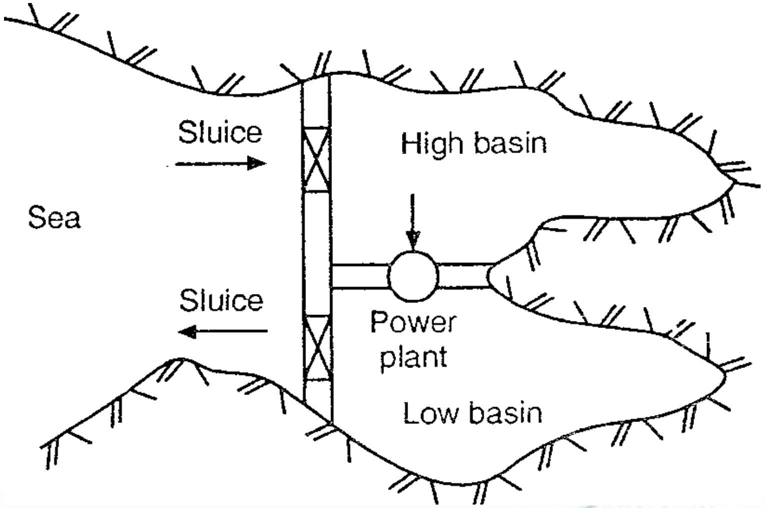
ii. Single-basin doule-effect plant ….cont'd

- The most practical method in double tide operation is by the use of the reversible turbine which can operate in both directions of flow. In double-effect operation, the output is variable and intermittent, but to a lesser extent than that in the case of the unidirectional flow power plant.
  Other advantages over the one-way plant are:
  a. The overall output from an equal turbine capacity is greater by 15% and may increase if each plant is designed to the most economic type specification .
  b. The period of operation is increased.
- The reversible turbines and other allied equipment cost a little more, this additional cost is offset by the above two advantages.
- Due to its large period of operation, the operating regime of power generation can be manipulated so as to offer power to any predetermined period, either to suit the demand or to suit the tides. La Rance power plant of 240 MW in France is working on this type of operation.

7.4 Tidal Energy Power Plants

iii. **Double-basin with linked-basin operation** A large basin is converted into two basins of suitable dimensions; one which is at higher level is called high basin and the other low basin. The scheme consists of three barrages, one separating the high basin from the sea and containing the filling gates, another separating the low basin from the sea and containing the emptying gates. The third barrage separates the high basin from the low basin and contains the powerhouse.

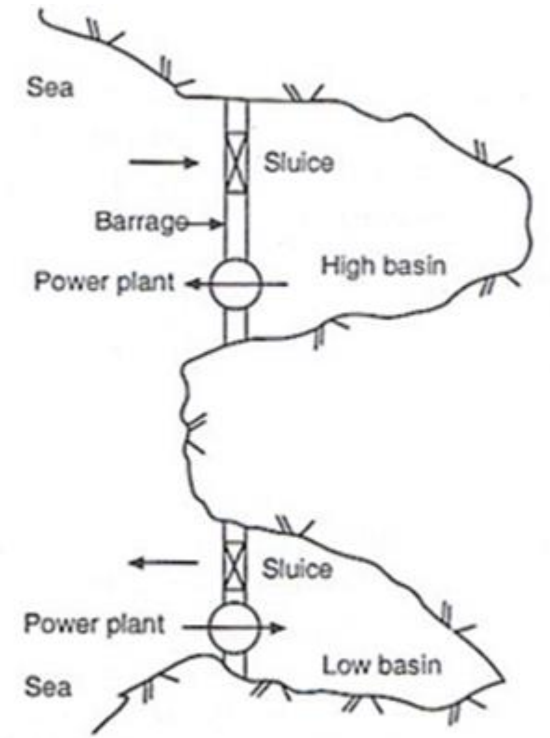
The upper basin filling gates are opened only during the time when the sea level is higher than the upper basin. The emptying gates of the lower basin are opened only when-the sea level is lower than the lower basin.



7.4 Tidal Energy Power Plants

iv. Double-basin with paired-basin operation

- Two separate single-basin single-effect schemes located at a distance from each other.
- Selected such that there is a difference in tidal phase between them and never exchange water, but are interconnected electrically.
- Both the basins operate in single-basin single-effect mode. One basin generates electrical energy during the 'filling' process while the other during the 'emptying' process.
- Its operation leads to a continuous output but the power supply remains irregular.
- Difficult to find two tidal sites close within each other having the requisite difference in time of high water.



Double-basin with paired-basin operation

7.4 Tidal Energy Power Plants

Three important components of a tidal plant:

i. A barrage to form a basin
ii. Sluice gates in the barrage for flow of water from the sea to the basin and vice-versa
iii. A powerhouse equipped with turbines, each coupled to a generator along with auxiliary equipment

i. Barrage (Dam or Dyke) The barrage should be constructed by the material available at site or from a nearby place. Barrages for tidal power projects have to withstand the force of sea waves, so the design should be suitable to site conditions and to economic aspect of development. The rockfill dams or barrages are preferred due to their stability against flows. The dyke (barrage) crest and slopes should be armored for protection against waves.

7.4 Tidal Energy Power Plants

Three important components of a tidal plant:

ii. <u>Sluices</u> Tidal power plants operate on the continuously varying difference in level at which the basin must be filled from the sea or emptied to the sea, as required by the operating regime of the power plant.

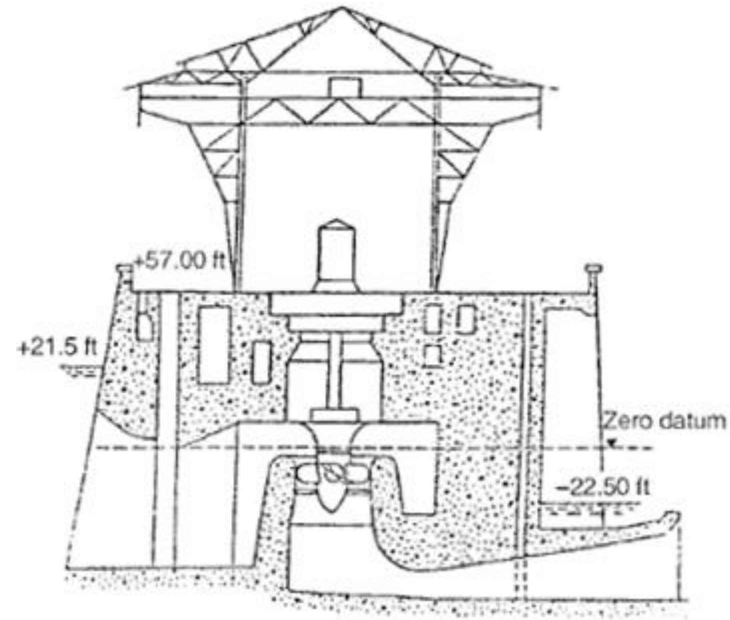
- This requires suitable sluice ways equipped with gates which can be operated quickly. These are required to be operated two or more times a day.
- There are two types of sluice ways,
  - type with crest gates and
  - submerged gates associated with venturi type.
- Sluice ways with crest gates are more prone to damage by wave action and masses carried by the flow. Vertical lift gates are the natural choice and can be fabricated from stainless steel.

7.4 Tidal Energy Power Plants

iii. <u>Turbines</u> The energy potential in tidal power development is exploited from low to very low heads, for which large size turbines are required. If the water head is more than 8 meters, a propeller type turbine is quite suitable because the angle of blades can be changed to obtain maximum efficiency while the water is falling.

The main aim in the design is to achieve as long a period of operation as possible. For low heads three types of turbines can be used; the selection is made according to the suitability, namely

- Bulb turbine
- Tube turbine
- Straight flow rim type turbine



7.4 Tidal Energy Power Plants – Advantages

1. Tidal power is predictable.
2. Available tidal power is firm as there are no wet or dry years, no dry or wet months, no influence of summer or winter on the availability of tidal energy.
3. It is free from pollution.
4. Tidal power is inexhaustible and a renewable source of energy.
5. Tidal power plants do not require valuable land, located on sea shores.
6. Tidal power when used in combination with a thermal plant can meet effectively the load demand.
7. After the capital cost of a tidal power scheme is paid off, the cost of power generated is very low.

Tidal Energy Power Plants – Disadvantages

1. Tidal power plant output varies with the variation in tidal range.
2. Tidal power supply is intermittent.
3. Capital cost of a tidal plant is not economical when compared with conventional sources of energy.
4. Silting of basins is a problem with tidal power plants.

7.4 Tidal Energy Power Plants

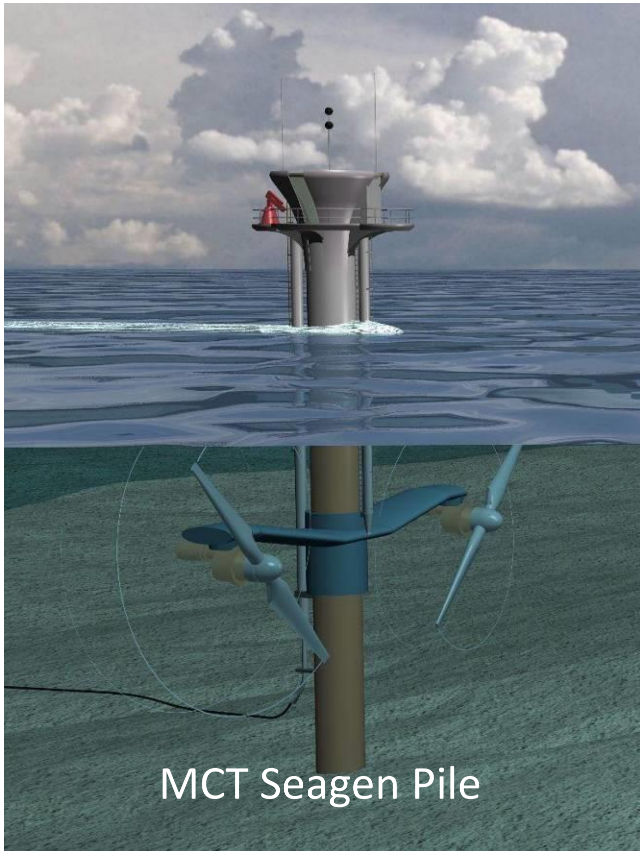
Country	Location	TWh/yr	GW
Canada	Fundy Bay	17	4.3
	Cumberland	4	1.1
USA	Alaska	6.5	2.3
	Passamaquody	2.1	1
Argentina	San Jose Gulf	9.5	5
Russia	Orkhotsk Sea	125	44
India	Camby	15	7.6
	Kutch	1.6	0.6
Korea	-	10	-
Australia	-	5.7	1.9

7.4 Tidal Energy Power Plants – Tidal Turbine Farm

- Tidal current turbines can be raised out of the water
- Prototype off the north Devon Coast, 300 kW Seaflow prototype

7.4 Tidal Energy Power Plants – Tidal Turbines (MCT Seagen)

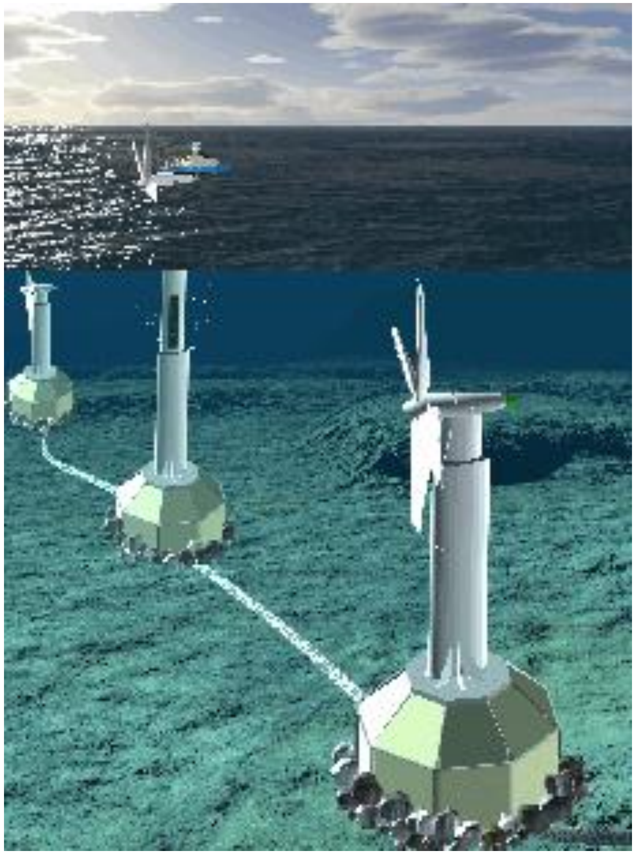
- 750 kW – 1.5 MW
- 15 – 20 m rotors
- 3 m monopile
- 10 – 20 RPM
- Deployed in multi-unit farms or arrays
- Like a wind farm, but
    - Water 800x denser than air
    - Smaller rotors
    - More closely spaced



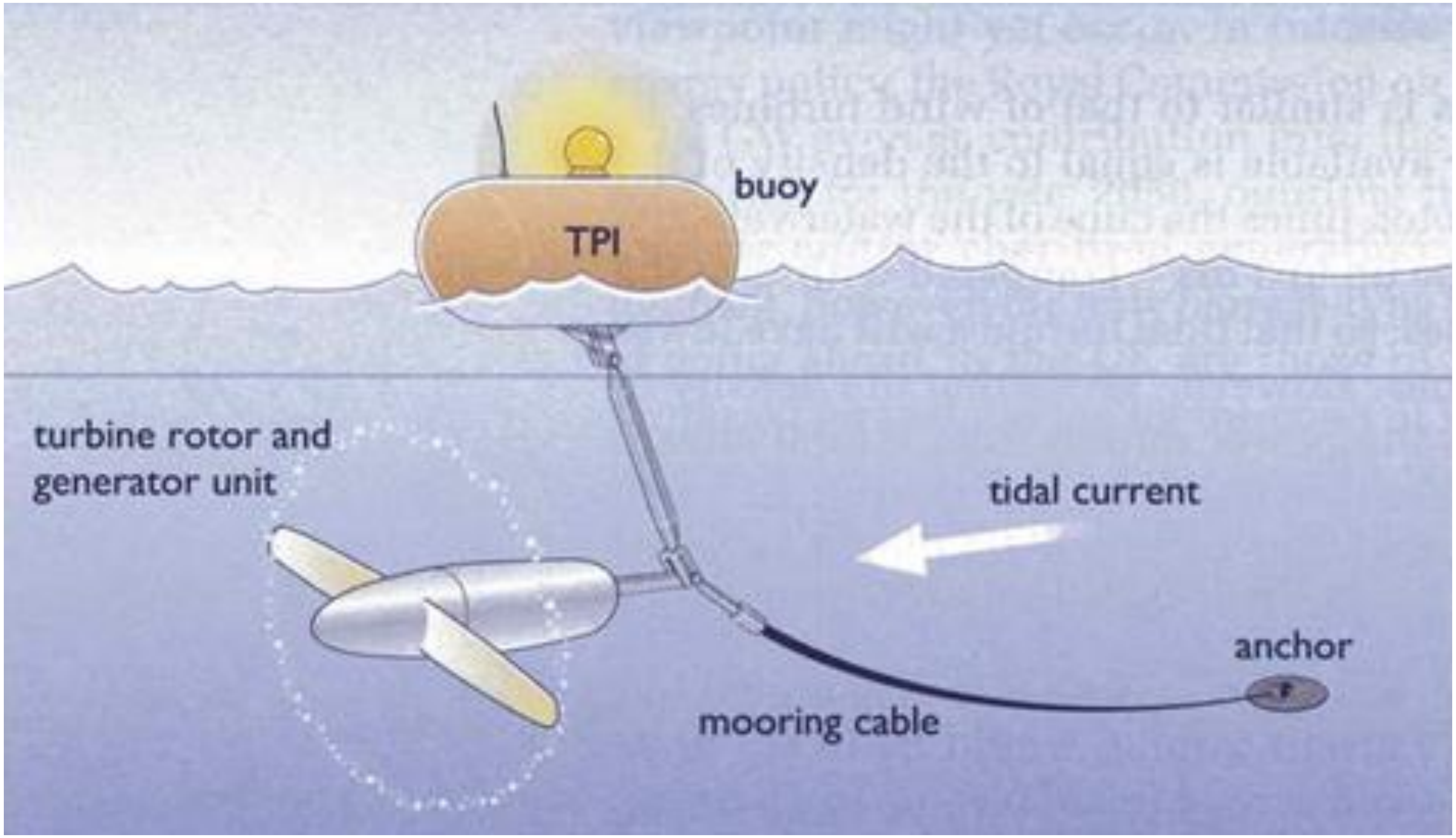
MCT Seagen Pile

7.4 Tidal Energy Power Plants – Tidal Turbines (Swanturbines)

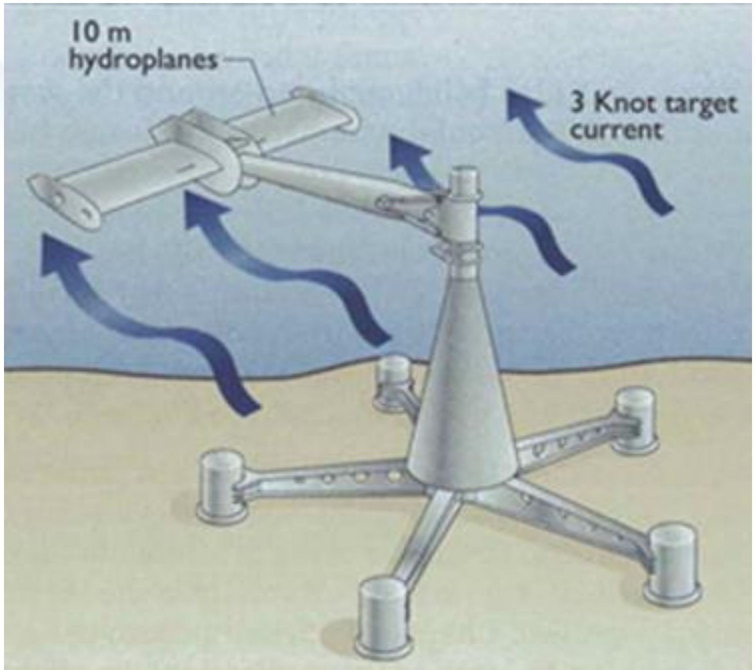
- Direct drive to generator
  - No gearboxes
- Gravity base
  - Versus a bored foundation
- Fixed pitch turbine blades
  - Improved reliability
  - But trades off efficiency

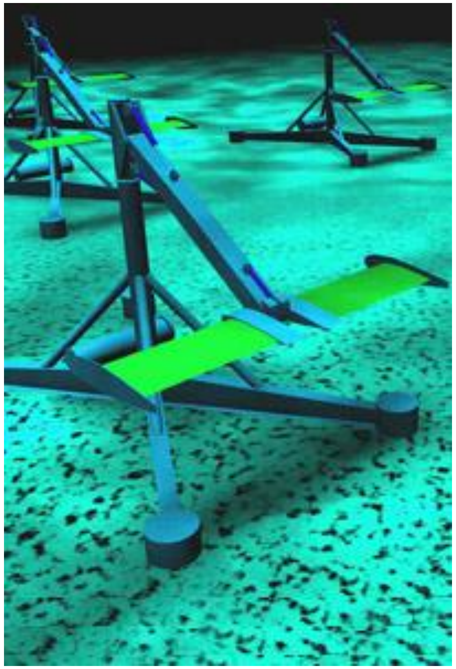


7.4 Tidal Energy Power – Deeper Water Current Turbine



7.4 Tidal Energy Power Plants – Oscillating Tidal Turbine



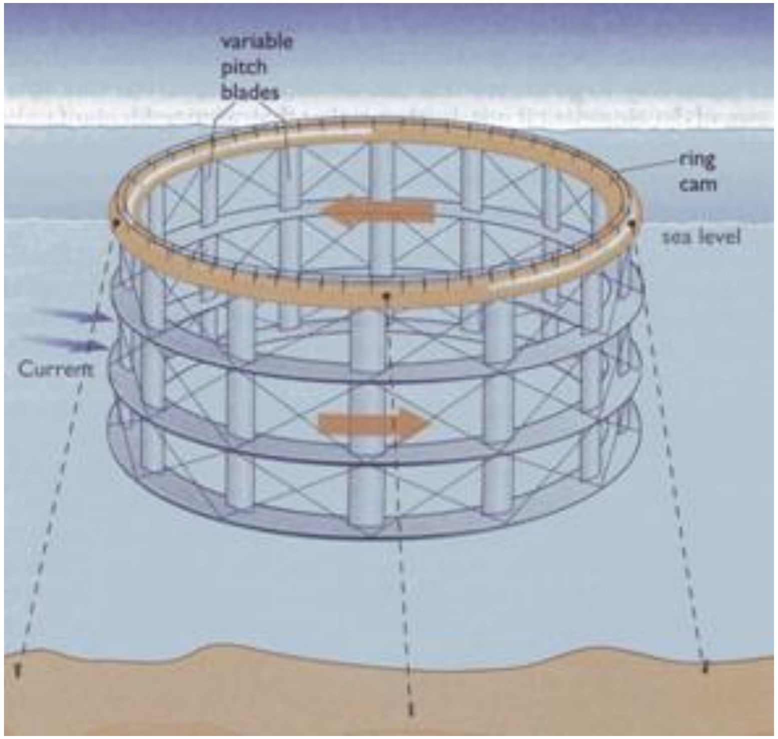


Stingray tidal generator oscillates up and down, 150 kW prototype (2003), Northumberland, UK

7.4 Tidal Energy Power Plants – Polo Tidal Turbine

Tidal current device 'the Polo‘ consists of a series of vertical-axis water turbine blades mounted in a cylinder-shaped structure, which can rotate on bearings in a tethered ring which floats on the surface.

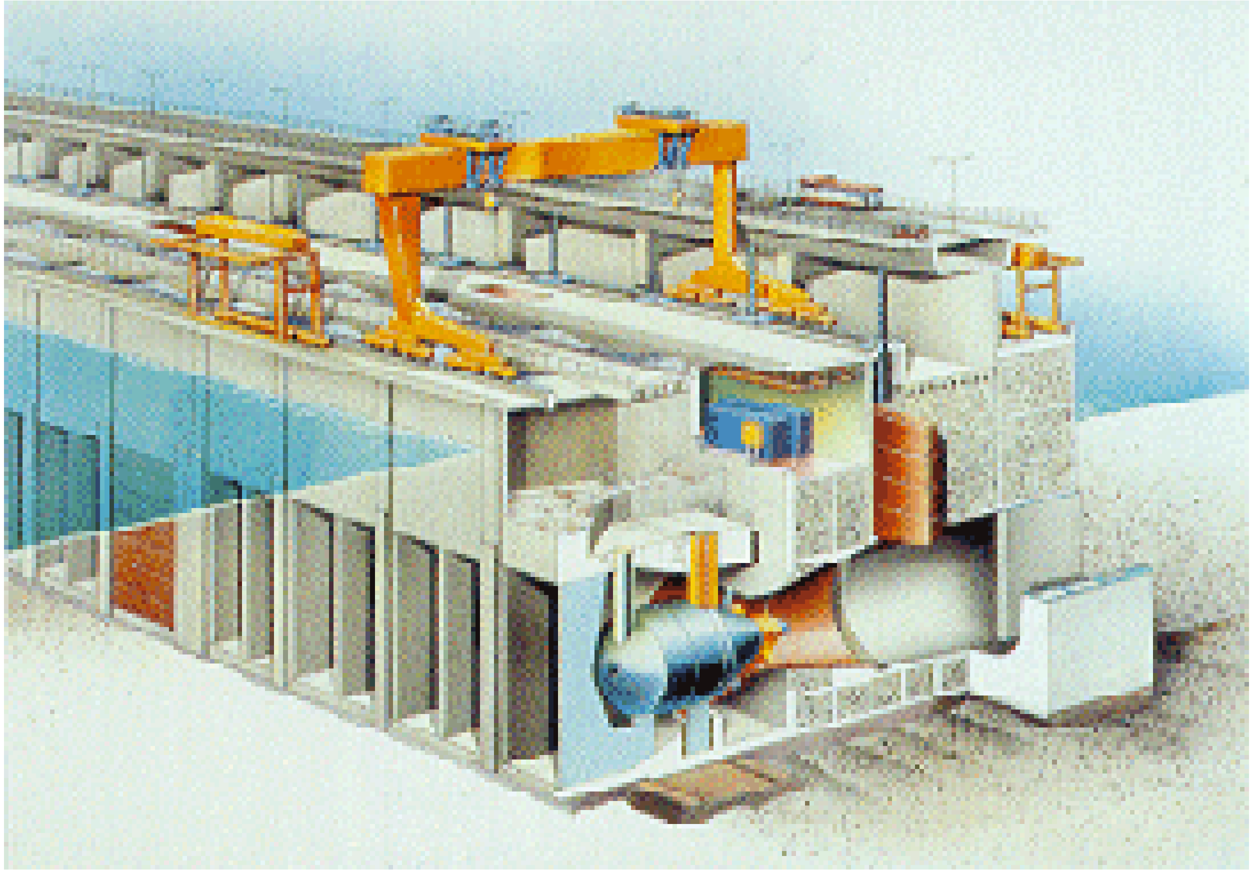
- Vertical turbine blades
- Rotates under a tethered ring
- 50 m in diameter
- 20 m deep
- 600 tonnes
- Max power 12 MW



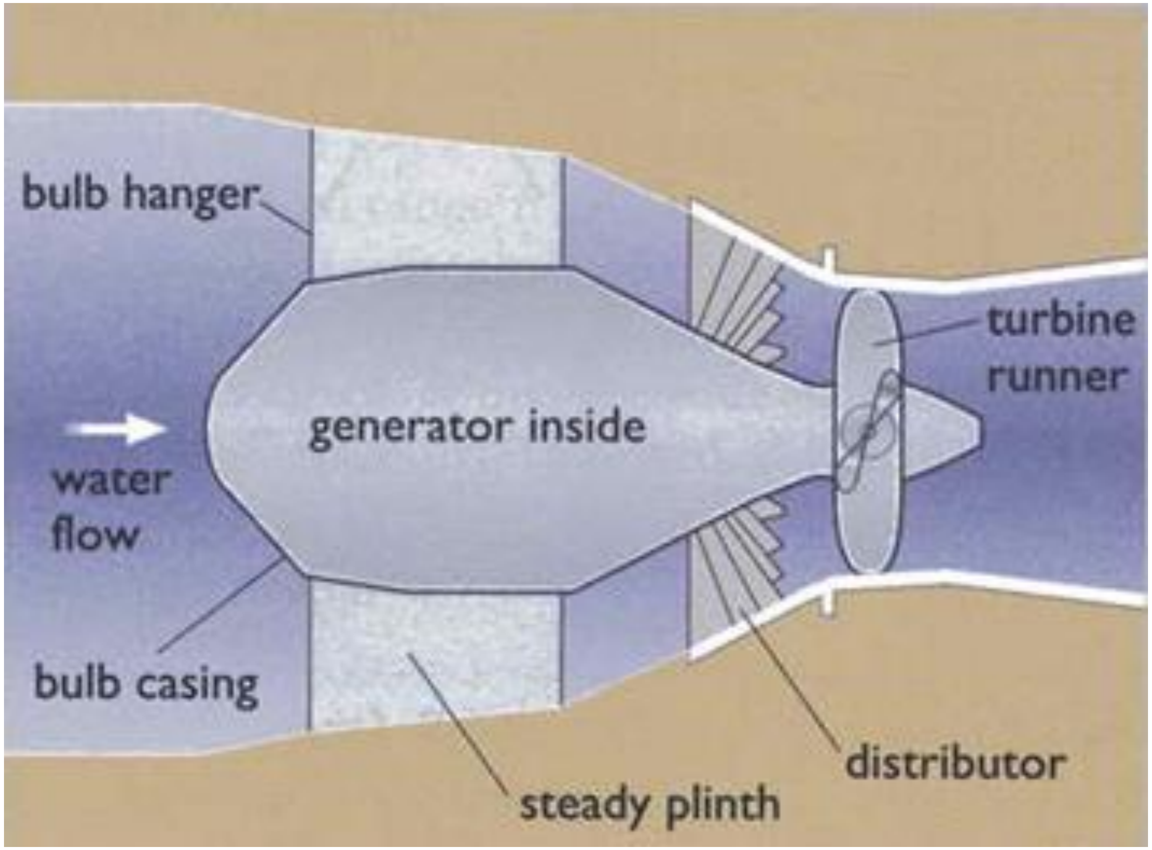
7.4 Tidal Energy Power Plants – Potential Tidal Barrage Sites

20 sites for possible tidal barrage stations

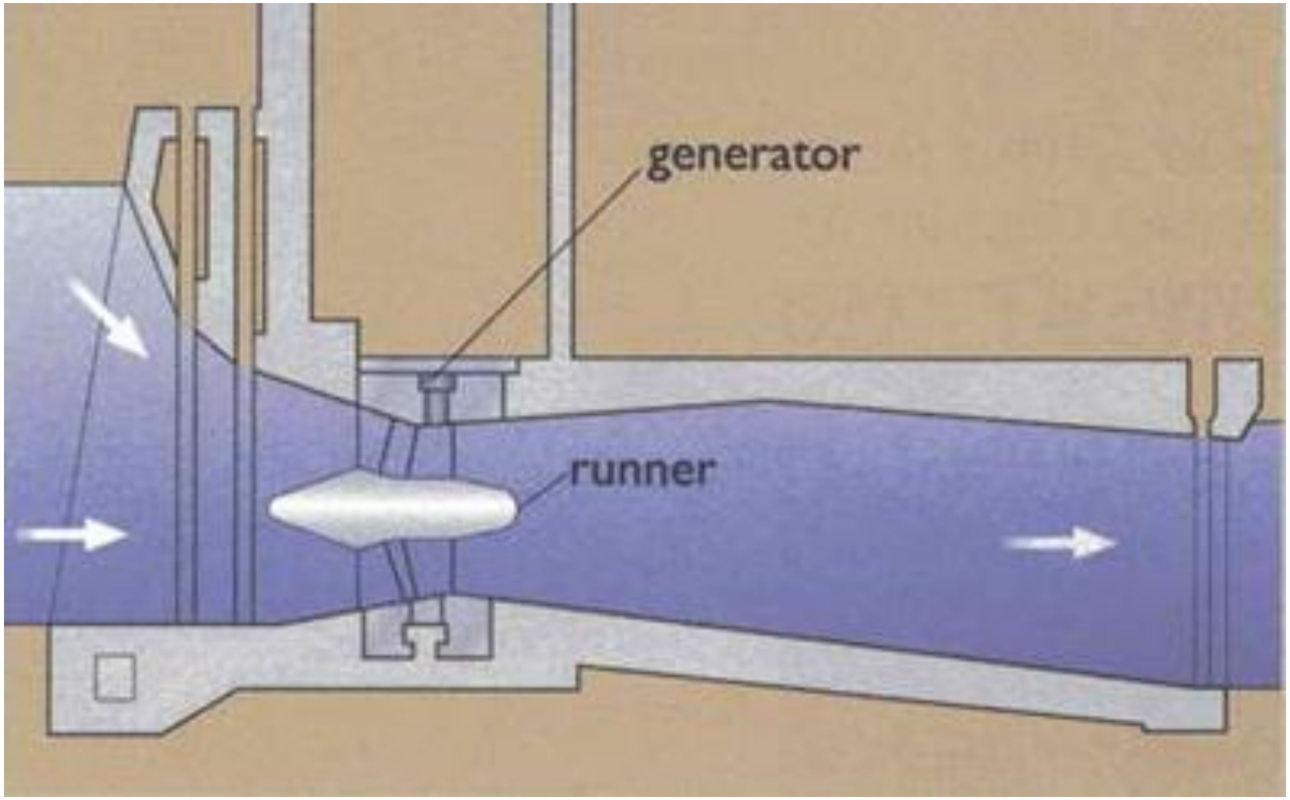
7.4 Tidal Energy Power Plants – Cross Section of a Tidal Barrage



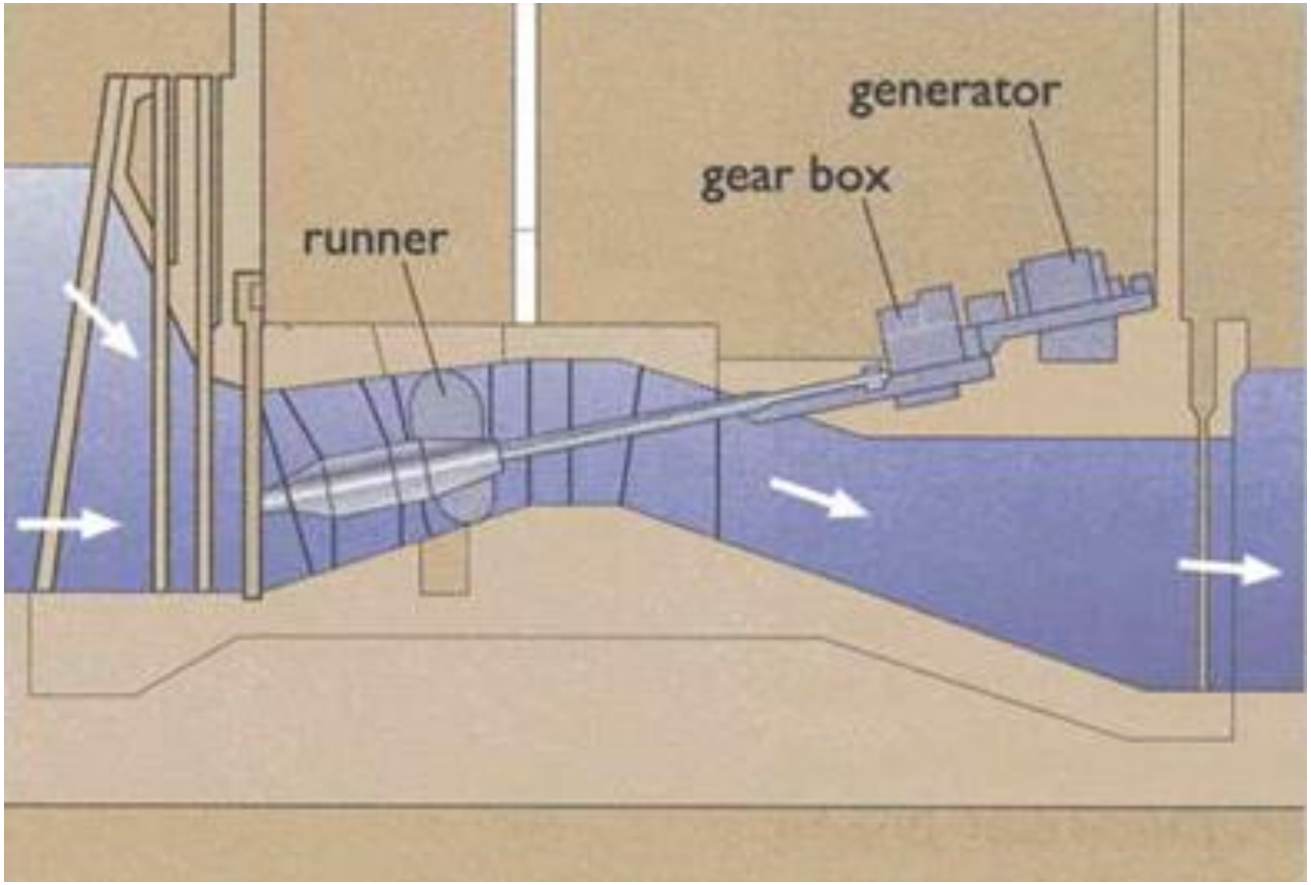
7.4 Tidal Energy Power Plants – Tidal Barrage Bulb Turbine



7.4 Tidal Energy Power Plants – Tidal Barrage Rim Generator



7.4 Tidal Energy Power Plants – Tidal Barrage Tubular Turbine

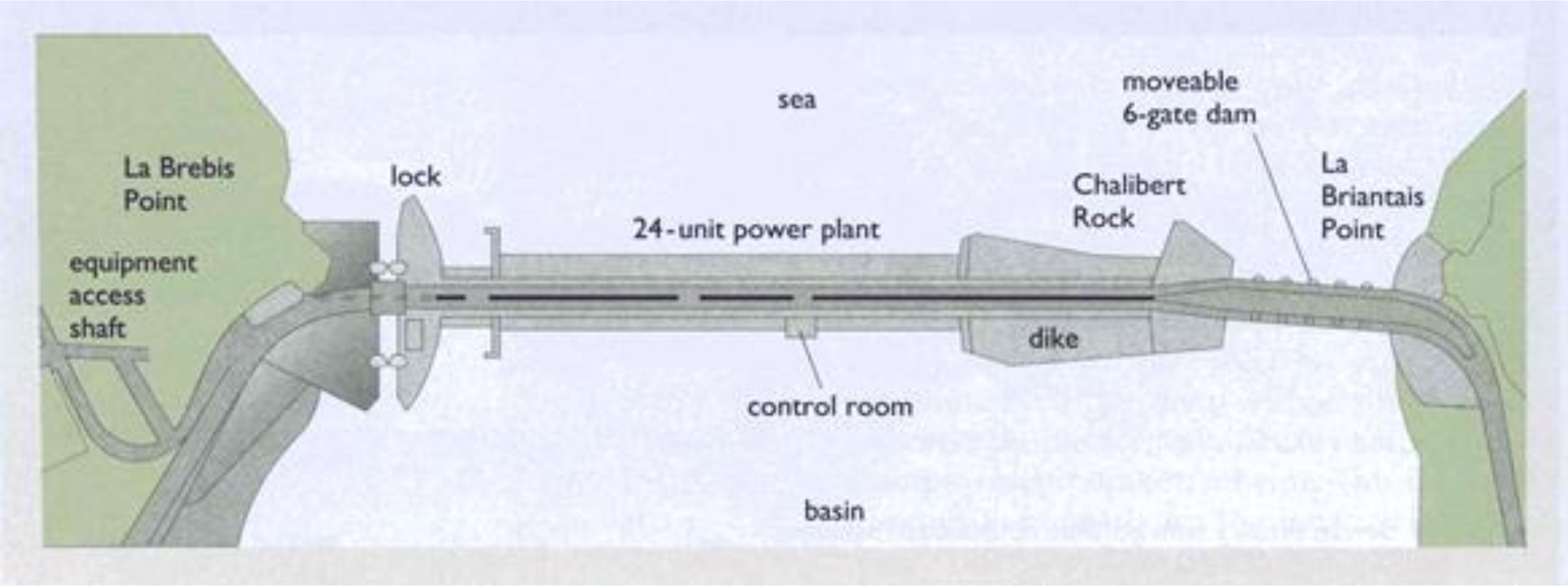


7.4 Tidal Energy Power Plants – La Rance Tidal Power Barrage

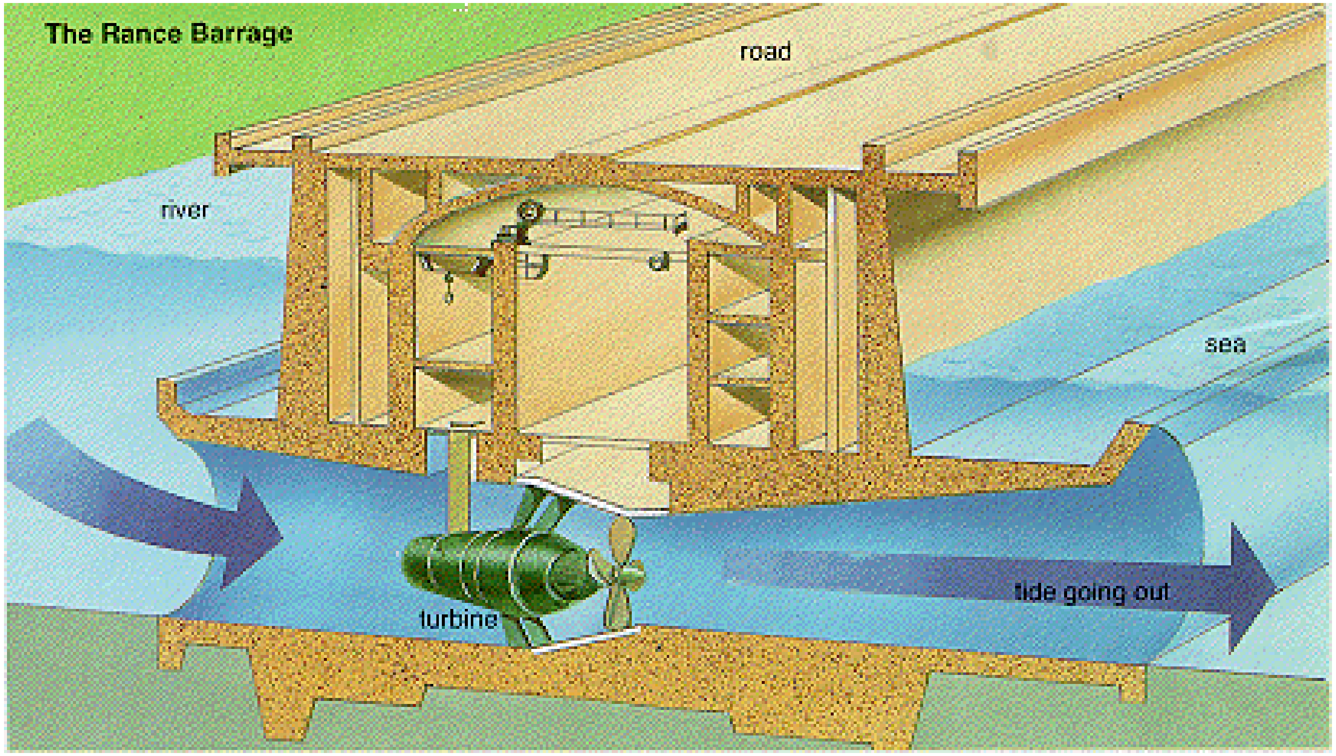
7.4 Tidal Energy Power Plants – La Rance Tidal Power Barrage

7.4 Tidal Energy Power Plants – La Rance, Saint Malo

7.4 Tidal Energy Power Plants – La Rance Barrage Schematic



7.4 Tidal Energy Power Plants – La Rance Barrage, cross section



7.5 Economics of Tidal Power

Tidal power, in its cheapest form can only be generated intermittently. To convert the intermittent low grade energy to guaranteed continuous energy, additional cost must be incurred. Another aspect is that due to the low generating heads, the cost of machinery and its supporting structure is high.

The cost economy guides that a small-scale tidal power development must be justified on its own merits, so that the unit construction cost can definitely be offset against the other consequent benefits. Planning need not be aimed at the cheapest power production, but towards the best benefit-to-cost ratio of the project. The benefits can be numerous and some of them may be quite tangible. There are some benefits other than the power benefit which can reduce the cost of energy to a competitive level.

7.5 Economics of Tidal Power

Major benefits that can accrue from tidal power are:-

1. It is a renewable energy source free from weather vagaries. The cost of energy produced is quite nominal, i.e. only the operational cost.
2. Performance of the plant is pollution free.
3. Tidal power combined with the pumped storage generation ensures continuous power supply
4. Road crossing on the barrage connects the isolated areas without constructing a bridge.
5. It improves the transport and navigational facilities.
6. Creates infrastructure for regional development.
7. Recreational facilities generate tourism potential.
8. Land reclamation of sea shore waste land is a long-term benefit.
9. Social and political benefits are quite substantial.

7.6 Tidal Energy in Malaysia

Preliminary study 5-m blade turbine by Yun Seng Lim and Siong Lee Koh (2009) across east and west Malaysia

- Barrage approach at 6 sites
  1. Power availability between 76.16% and 63.33% in Table 1
  2. Sejingkat site average monthly yield 14,970 kWh in Table 2
  3. Energy for 75 households for a month @ 220 kWh per household
- Tidal Stream approach at 4 sites
  1. High power availability Sandakan @ 584 hr/month or 80% in Table 3
  2. Lowest 79% in January and February
  3. High power availability 81% Mar, Aug, Sept, Oct and Dec
  4. Average monthly yield 14,502 kWh/yr in Table 4

7.6 Tidal Energy in Malaysia

Table 1

POWER AVAILABILITY FOR SIX SITES USING BARRAGE APPROACH

Date	Monthly Availability (%)					
	Sejingkat	Pelabuhan Kelang	Pulau Langkawi	Tawau	Kukup	Johor Baru
Jan	76.10%	76.41%	60.01%	64.45%	65.86%	62.95%
Feb	75.80%	74.53%	63.73%	63.70%	66.84%	61.00%
Mar	75.16%	74.53%	60.95%	65.62%	66.58%	60.57%
Apr	76.18%	75.10%	57.44%	61.67%	65.11%	62.10%
May	76.15%	75.88%	57.52%	61.08%	63.35%	63.65%
Jun	74.97%	76.91%	61.54%	66.44%	67.25%	64.31%
Jul	76.07%	76.01%	57.26%	62.37%	67.94%	62.89%
Aug	76.61%	74.40%	57.76%	62.63%	64.85%	62.74%
Sep	76.39%	74.01%	59.69%	66.38%	68.67%	63.64%
Oct	75.83%	74.19%	61.63%	62.67%	63.71%	65.77%
Nov	77.61%	75.24%	60.66%	63.07%	62.24%	65.89%
Dec	76.91%	76.96%	59.48%	64.05%	65.58%	64.50%
Average	**76.15%**	**75.35%**	**59.81%**	**63.68%**	**65.67%**	**63.33%**

7.6 Tidal Energy in Malaysia

Table 2

MONTHLY YIELDS FOR SIX SITES USING BARRAGE APPROACH

Date	Yields (kwHr)					
	Sejingkat	Pelabuhan Kelang	Pulau Langkawi	Tawau	Kukup	Johor Baru
Jan	477.74	415.91	134.82	183.95	192.14	132.20
Feb	451.20	465.65	77.01	228.92	195.70	159.89
Mar	401.22	522.44	185.24	257.53	229.72	224.42
Apr	489.06	447.16	163.08	205.66	235.79	168.64
May	470.76	406.01	122.26	182.11	175.95	180.89
Jun	399.05	324.28	115.95	156.86	163.26	152.43
Jul	497.05	354.58	109.83	155.84	194.00	156.73
Aug	538.21	421.81	147.29	206.63	206.83	209.03
Sep	492.39	440.49	168.81	246.54	218.89	204.61
Oct	435.21	483.47	187.60	248.20	226.38	224.62
Nov	522.84	404.70	153.98	191.58	163.79	199.43
Dec	543.40	387.50	120.52	168.36	169.94	192.29
Total	**5,718.14**	**5,074.00**	**1,686.38**	**2,432.17**	**2,372.39**	**2,205.18**
Average	**476.51**	**422.83**	**140.53**	**202.68**	**197.70**	**183.76**

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7.6 Tidal Energy in Malaysia

Table 3

POWER AVAILABILITY AT 4 SITES AROUND MALAYSIA USING THE TIDAL STREAM APPROACH

Month	Total Monthly Availability			
	Kelang	Melaka	Pulau Pangkor	Sandakan
Jan	16.73%	41.81%	56.24%	78.48%
Feb	20.31%	42.75%	54.75%	77.74%
Mar	21.71%	44.56%	55.67%	81.17%
Apr	20.68%	43.90%	55.74%	80.23%
May	17.05%	42.06%	57.41%	79.95%
Jun	13.38%	40.97%	57.29%	78.80%
Jul	17.34%	43.34%	57.29%	79.28%
Aug	23.26%	45.60%	58.12%	80.85%
Sep	23.84%	45.28%	57.03%	81.48%
Oct	20.78%	44.71%	56.90%	81.45%
Nov	15.17%	43.53%	58.87%	80.31%
Dec	13.24%	41.33%	58.79%	80.61%
Average	**18.62%**	**43.32%**	**57.01%**	**80.03%**

Problem 7.1: Tidal basin average power output

A simple single-basin type tidal power plant has a basin area of 22 km^2. The tide has a range of 10 m. The turbine stops operation when the head on it falls below 3 m. Calculate the average power generated during one filling/emptying process in MW if the turbine-generator efficiency is 74%. Density of sea water is 1025 kg/m^3. Duration of time for single effect is 6 hours and 12.5 minutes.

Energy potential $\boldsymbol{E_f} = A_z.\rho.g\int_{z=0}^{z=R} z.dz = \frac{1}{2}\int_{3}^{10} z.dz = \frac{1}{2}A.\rho.g(10^2 - 3^2)$

$$= \frac{1}{2} \times 22 \times 10^6 \times 1025 \times 9.81(10^2 - 3^2) = 10.065 \times 10^{12}\ \mathrm{J}$$

Average Power $\boldsymbol{P_f} = \boldsymbol{E_f}/\boldsymbol{t} = 10.065 \times 10^{12}/22350 = 450.35\ \mathrm{MW}$

Turbine generator efficiency 74%

Power Output $P = 450.35 \times 0.74 = \mathbf{333.25\ MW}$

Problem 7.2: Tidal basin yearly power output

For Rann of Kutch the basin area of a tidal project is 0.72 sq. km, with a difference of 6 m between the high and low water levels. The average available head is 5 m and the system generates electric power for 4 hours in each cycle. Assuming the overall efficiency as 80%, calculate the power in kW at any point of time and the yearly power output. Density of sea water is 1025 kg/m^3

$$Volume\ of\ basin\ AH = 0.72 \times 10^6 \times 6\, m^3$$

$$Average\ discharge\ Q = \ AH/t = 0.72 \times 10^6 \times 6/4 \times 3600 = 300\, m^3/s$$

$$Power\ at\ any\ instant\ P = \frac{\rho Q H'}{75} \times \eta \times 0.736\, kW = \frac{300 \times 1025 \times 5}{75} \times 0.736 \times 0.8 = 12{,}095\, kW$$

$$Energy\ generated\ per\ tidal\ cycle = 12{,}095 \times 4 = 48{,}380\, kWh$$

$$Total\ number\ of\ tidal\ cycles\ in\ a\ year = 705$$

$$\therefore Yearly\ energy\ generation = 48{,}380 \times 705 = 341.08 \times 10^5\, kWh$$

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