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Large tidal plants may supply 1,000 TWH / year

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Many studies of tidal plants have been made fifty years ago : they were usually devoted to sites with average tidal head over 6 m and reduced works at sea: estuaries such as La Rance (France) or Severn (U.K.) were favoured: preferred corresponding operation was using flow from a high basin to low sea level, supplying power 4 hours from 12. Such solutions had 2 drawbacks: power supply poorly adapted to needs and modified shore tidal ecosystems.
Beyond that the power cost was usually higher than from thermal plants and very few plants were built, the main one being the Rance plant in France supplying 0,5 TWH/year with 240 MW.
The world theoretical tidal potential is in the same range as the traditional hydropower potential. A new approach of tidal plants based upon solutions existing now and using new operating methods substantiates the possibility of over 1,000 TWH/year of cost efficient tidal energy with limited environmental impact and power supply well adapted to requirements. Over 15 countries may be involved. Tidal plants with heads as low as 4 m may be cost efficient.

1) Acceptable cost

As far as the cost of thermal power has been lower than 5 cents of U.S.$ /KWH, low head tidal plants could hardly be cost efficient because the investment of the tidal plan itself, in the range of 1,000 U.S.$ /KW for 2,000 or 2,500 KWH/year did represent an investment per yearly KWH close to 0,5 $ and a cost per KWH (about 10% of it) close to 5 cents of $, leaving little credit for the cost of dykes at sea.

The situation is now totally modified with the high cost of fuel and the much higher cost than most countries will accept for renewable and environment friend energy. A rough evaluation can be made with an acceptable cost of tidal energy of 10 cents of $ par KWH, leaving a credit of 5 cents of KWH (i.e. a credit of investment of 0,5 $ per yearly KWH) for dykes at sea. As will be justified below, a possible yearly power supply by km² of tidal basins is close to 50 GWH/year for an average tidal range H of 8 m and is proportional to H².
The cost of dykes at sea will vary considerably, most often between 20 and 100 millions $ /km. For a dyke cost of 50 millions $ /km and a tidal range of 8 m, each km² of basin will justify $50 \times 10^6 \times 0,5 = 25$ millions $, i.e. 0,5 km of dyke at sea. Most onshore sites are more favourable and offshore atolls of 10 km diameter require less than 0,5 km dyke per km² and may supply 4 TWH / Year.
For a tidal range of 4 m offshore sites are too expensive because their acceptable ratio is 8 km² of basin per km of dyke but many onshore sites including large basins with dykes 10 km at sea may be cost effective.
Many opportunities which were not studied 50 years ago may thus deserve a new analysis: they may be favoured by new operating solutions and by huge progresses since 50 years in low head power plants, large works at sea and low cost electric power transport along thousands of km.

2) Reference to La Rance Plant

The largest existing tidal plant is La Rance Plant in North West of France.
For a tidal average range of 8,5 m it had been initially designed with 400 MW. As the cost per KWH was higher than thermal power, the investment was finally reduced to 240 MW and the yearly output to 500 GWH /year.
The plant is usually operating essentially as high basin and sometimes as low basin. But its limited capacity and an area at low level much less important than at high level do not favour there the operation such as presented in 3.1 below.
The example of La Rance is sometimes used for advocating operation of a single basin only as high basin: this appears neither favourable to the economy nor to the environment; for a single basin, if the area at low level is a large percentage of the area at high level the solution presented below may quite double the output for a same area and reduces considerably the cost per KWH: many designs could be improved accordingly.

3) New operating solutions

There are many options with one or several basins; 2 efficient solutions with single basins are analysed below because they may be adapted easily to most sites and may be combined together physically or electrically.

3.1. Single basin Operating Bothways (S.O.B.)

Calculations below are based upon 2 equal tides per day (in fact 12 hours 25 minutes per tide) which is the most usual case for sites with tide range over 4 m.
The theorical energy potential for each half tide is (in MWH) for an area S (km²) a tidal range H (m) and a water density 1,035.

$$\frac{S \times 10^6 \times H \times 0{,}5\ H \times g \times 1{,}035}{3{,}600 \times 10^3}$$

to be multiplied by 1,410 half tides per year.
The theoretical yearly energy is thus in GHW close to $2\ S\ H^2$
The proposed solution is to use turbines operating both ways during a same tide from the basin to low sea level and from high sea level to the basin (as per drawing 1 attached).

The turbines supply power during about 2 x 3 hours per a 12 hours tide. The net supplied energy is limited to about 40% of the potential (i.e. $0{,}8\ S\ H^2$) due to power units output, to the fact that the sea level is not always minimum or maximum, the fact that the basin is not totally full or empty and the impact of low tides.
The net supply may be increased to $0{,}9\ S\ H^2$ if pumping one hour during each half tide.
The yearly supply is thus over 50 GWH / year per km² for H = 8 m, requiring a plant capacity of about 15 MW per km². These figures are divided by 4 for H = 4 m.

The drawback of this solution is that it supplies only power half time. It may be used as such in countries using mainly thermal power or it may be combined with other tidal schemes as below or with pumping onshore or offshore plants.

A key advantage is the fact that within the basin the curve of water level is very similar to the sea level tidal curve, postponed by 3 hours. There is thus a very reduced environmental impact and this solution may easily be used onshore.

3.2. Very High Basin and Very Low Basin (V.H.B. and V.L.B.)

The basins may be linked physically or only electrically.
The average level is kept over the high sea level for the high basin and under the low sea level for the low basin.
The high basin may for instance be operated between 0,25 H under the high sea level and 0,5 H over the high sea level (drawing 2). The level is raised by pumping along about 3 hours when the sea level is high. Power is supplied along 6 hours when the sea level is lower than medium level.

The low basin is used in a similar way; the energy for pumping in each basin being supplied by the other basin. It is possible through adjusting the power supply either to have all day the same net power supply or to supply power according to requirements and sales rate.
If the basins are linked physically it is possible to add a plant between basins for extra peak power.
As compared with the single basin operating both ways, this solution has 2 drawbacks:

- The cost pert KWH is slightly higher because the required plant capacity is higher for a same yearly supply.
- The water level curve within each basin is not the same as the sea curve and it modifies environment if used onshore.

But there is a great advantage of power guarantee and flexibility.

In populated areas, this solution may be used in offshore sites combining the 2 basins, or associated with a single basin onshore operating both ways (drawing 3).
In remote areas, this solution may possibly be used onshore, either linking electrically 2 onshore simple basins in very favourable sites, or as per drawing 4.

4) Turbines and generators

For the high and low basins, the units will operate as turbine and pump. For the single basin solution the turbines will operate both ways and the units should preferably operate as well as pumps. Such equipment is used successfully since 40 years in La Rance in France (bulb units); it may be improved, for instance with gears allowing different rotation speeds for the turbine and the generator or with variable frequency generation allowing better outputs for the various operating ways and heads.
For important schemes and average tidal range between 4 and 8 m, the usual power of units will probably be between 20 and 50 MW. The great number of necessary units may favour costs reduction.
The successful operation of La Rance along 40 years demonstrates the possibility of safe operation of units in sea water.

5) Civil engineering and construction methods

The power plants may be built in situ within cofferdams or prefabricated in caissons (steel or reinforced concrete) and floated to site; the caissons solution being particularly adapted to remote sites: caissons with several turbines totalling 200 MW may be used.
Great progresses have been made since 50 years for breakwaters and offshore works. Building dykes at sea with water depths up to 50 m can be based on well known technology. The cost per m is about proportional to the dyke height.
As for embankment dams, the choice of solutions is linked with available materials. The part of dykes underwater may be made by dredged sandy materials often available in tidal areas. The upper part may use rockfill or prefabricated reinforced concrete caissons. Waterproofing may use grouting or diaphragm walls. The necessary waterproofing is not as perfect as for high onshore dams because the waterhead is low and some leakage economically acceptable.
The closure of basins will be easy if using the power units openings for keeping low head and reduced water speed in the closure breach.

6) Environment

- The area of basins will be between 20 and 80 km² per TWH / year according to the tidal range; the total existing onshore hydropower requires over 300,000 km² for 2,700 TWH /year, i.e. over 100 km² / TWH / year as average.

- Tidal power requires no resettlement.

- Tidal onshore conditions are not seriously modified by the single basin solution presented above or by solution per drawing 3; the high waves are avoided and it is possible also to avoid exceptional high water levels, and thus the impact of general ocean level increase.

- There may be detrimental impact on fish but the total area of tidal basins will be limited to 1/10,000 of oceans area and basins offer huge facilities for aquaculture.

- Another impact may be the need of dredging large quantities of materials for dykes and opening rock quarries. The quantities per KWH are similar to quantities used for many traditional river equipments.

7) World potential

The average tidal head is over 4 m for more than 500,000 km² at sea; along 20,000 km of shore length, the theoretical energy per km varies from 0,5 to 5 TWH / year, with 1 TWH / year average (i.e. a total of 20,000 TWH / year as compared with 40,000 for the theoretical onshore hydropower potential) (drawing 5).

- A part of the potential is in places with favourable climatic conditions for construction, including high tidal ranges (France, U.K., Southern Canada, India, Australia, Argentina) or medium tidal ranges (Brazil, Columbia, Ireland, China, Bangladesh, Myanmar; Korea).
Many sites are favourable and close to power needs; an acceptable cost of 10 cents of $ / KWH could there be justify up to 500 TWH / year before 2050.

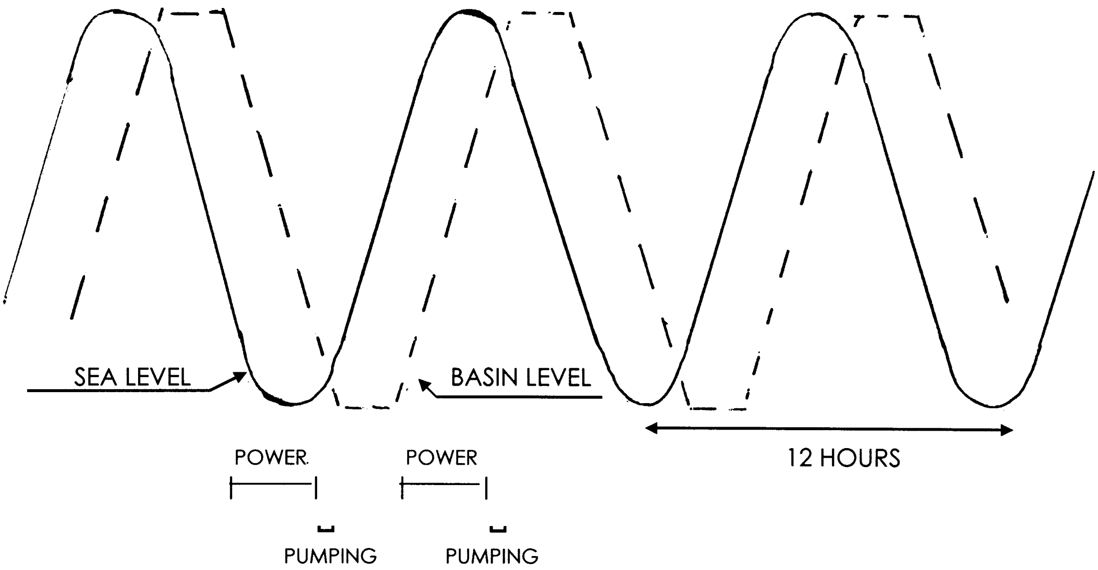
- Very huge potential is in very cold places such as in Russia (Barentz Sea or Hokhotsk Sea), Alaska, Northern Canada. Many large sites are very favourable to power production. There are technical solutions available but the cost may be higher due to climatic conditions. However large dams have been built successfully in difficult conditions (Siberia, Canada, Himalayas) and some very favourable tidal sites deserve a new study in present economical conditions. Within 50 years it is also likely that the average temperature in these areas will increase by 5° and construction conditions will be much easier. It is thus possible that 500 TWH / y may be developed there along the century, some of them before 2050, for instance in Barentz Sea or Southern part of Alaska.

Conclusion

Tidal energy is one of the most attractive renewable energies. It does not require new technologies; but studies for optimizing equipment and operation and construction methods would be justified.
A target up to 1,000 TWH / year along the century appears realistic, to be compared with 5,000 TWH / year of new hydropower schemes.
The environmental impacts appear low. The cost appears similar to or lower than wind power. It is often possible to combine both energies, placing wind plants on tidal dykes or close to them, thus reducing the cost of wind power.
The possibility of tidal guaranteed power and peak generation is a key advantage as compared with wind power.

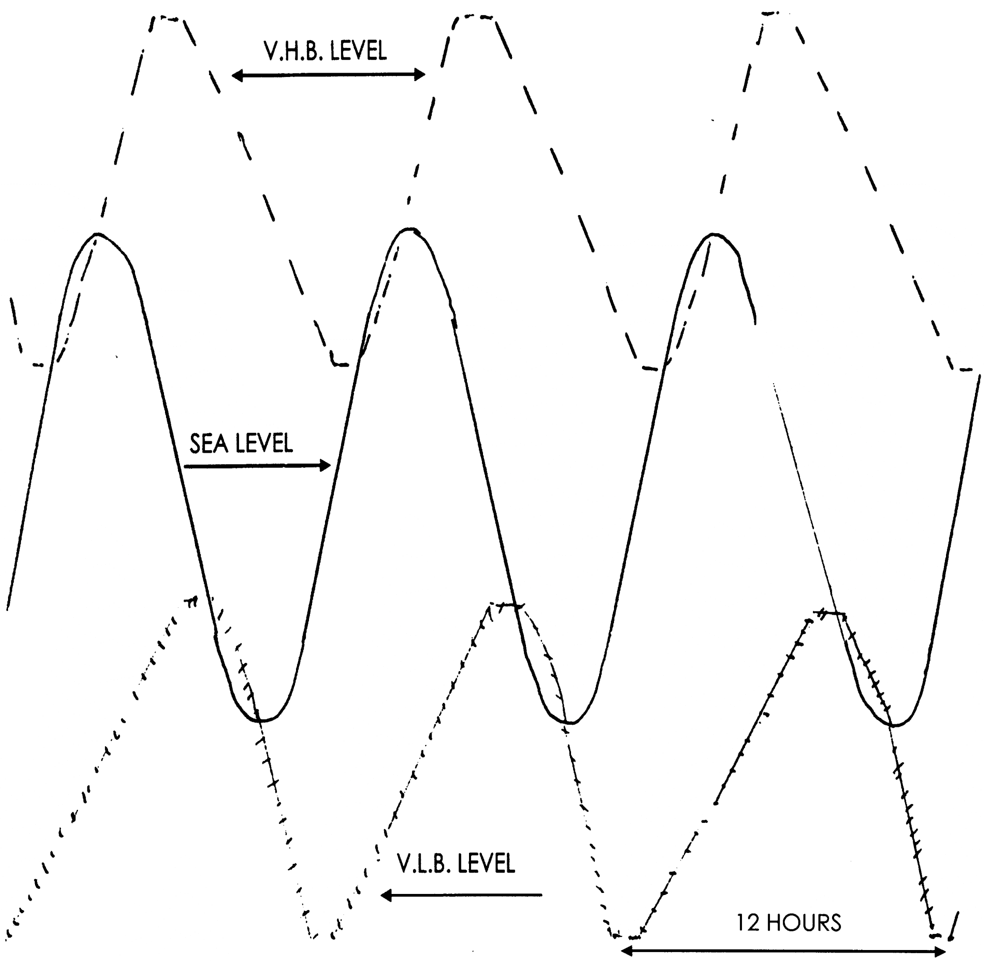
1

SINGLE BASIN OPERATING BOTH WAYS



VERY HIGH BASIN (V.H.B.) associated with VERY LOW BASIN (V.L.B.)

2



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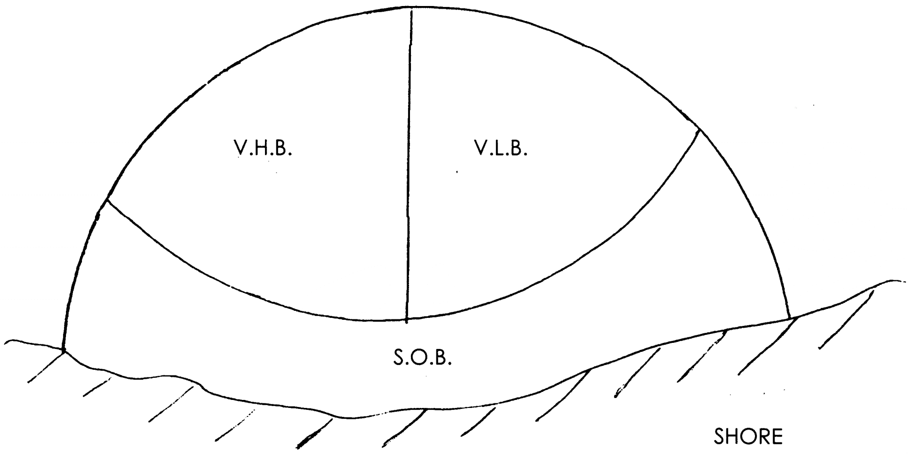

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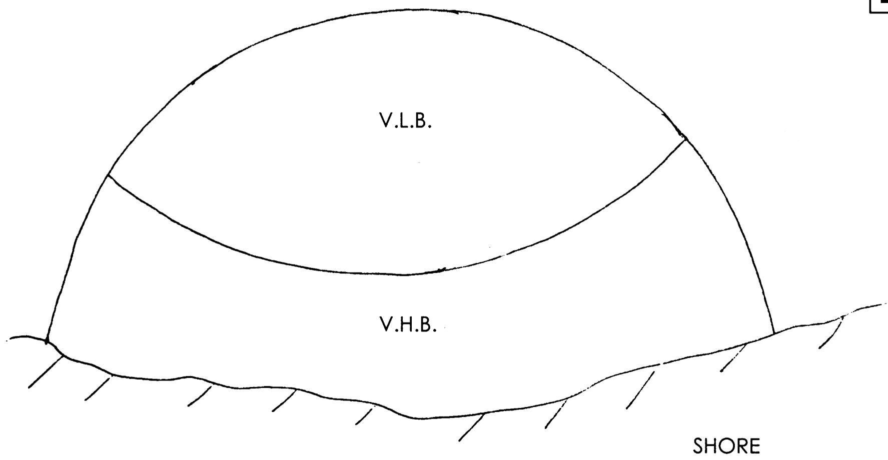

5

AVERAGE TIDAL RANGE OVER 4 m