FUTURE OF TIDAL POWER

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Keywords: Tidal Energy, Renewable Energy, Ecologically Benign Energy, Economic Validation of TPP Construction, Global Role of TPPs

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Summary

The concept of world power for the 21st century envisages prevailing development of renewable and ecologically benign sources of energy, the main of which at present is tidal energy in terms of engineering aspects of its harnessing. Utilization of tidal energy at present is possible at 140 sites on the shores of the world ocean with total potential of 811 GW, which is about a quarter of total present capacity of all the power stations in the world. Ten TPPs are existing now in the world as part of power grids: Rance TPP (from 1967), the Kislaya Guba pilot TPP in Russia (1968), 7 TPPs in China (1971-1978) and the Annapolis TPP in Canada (1984). Design of the following 6 large TPP have been prepared: the Cobequid (4 GW) and Cumberland TPPs (12 GW) in Canada, the Tugur TPP (8 GW) in Russia, the Garolim TPP (0.6 GW) in Korea, the Mersey (0.7 GW) and the Severn (8.6 GW) TPP in England. Thirty three year operation of pilot TPPs and the following experience, gained in designing of large TPPs have validated technical, energy, social and, which is the most important, economic viability of TPPs.

Due to testing of effective technologies and new hydroelectric equipment at TPPs, it became possible to decrease significantly (2-2.5 times) capital costs of TPP construction, which at present do not exceed those of equivalent HPPs; and cost of TPP energy at present is the cheapest in the power grid as compared to the energy costs of other types of power stations. For utilization of this potential in the global scale it seems to be necessary to attract not only private investors for TPP construction, but also the governments of the interested countries with moderate discount rates.

1. Comparison of Tidal Energy with Other Types of Ocean and River Energy

At present real technical potential of TPP construction is considered at 140 sites on the shores of the world ocean with total capacity of 811 GW and 2040 TWh annual output. The gross theoretical potential of tidal energy is estimated by different authors to be in the range of 2400-4000 GW, comparable to theoretical hydroelectric maximum capacity

(4000 GW).

The power potential of various kinds of ocean energy is given in Table 1. The data demonstrate that tidal power potential is comparable with other kinds of ocean energy, except for thermal and salinity gradients, but the use of the latter seems to be unlikely in the near future. The possible use of the thermal gradient is possible (See *Natural Temperature Differences as an Energy Source*), as is the use of energy of biomass (See *Energy from Biomass*), but it can be realized only in the tropics (with difference of temperatures in surface and deep layers of water not less than 18°C).

Type	Theoretical potential, TW
Thermal gradients (OTEC)	40 000
Salinity gradients	1400
Marine bio-conversion	10
Marine currents	5
Tides	3
Ocean waves	2.5

Table 1. Power potential of ocean energy (according to V. Lyatkher's data)

Contemporary designs show wave energy to be used in rather considerable amounts (See *Wave Energy*). But this energy complements tidal energy as the latter may be utilized on restricted sections of the shoreline with high tides, while wave power stations may be constructed over lengths of hundreds of kilometers, including disposition in front of TPPs, facilitating their operation by dissipation of wind waves which are undesirable for TPPs. For example, in India, in Kerala state, a wave power station is constructed at a distance of 45 m in front of the fish port breakwater. In the same way in the Tugur TPP design a number of wave power stations are proposed to be built to dissipate the wave energy in front of the TPP.

The contemporary design studies and existing test installations (Salter's Duck, Cockerell Raft, Russel's Energy Converter in the UK, Masuda Buoys in Japan, etc.) from the engineering point of view make it possible to construct a number of wave power stations. Therefore, the comparison with TPPs should be made only be considering economic efficiency. The overall estimate of wave energy, according to the latest UK studies, shows that the total technical potential may be 10-14 GW, that is, up to 7-9.3 kW per 1 m of the shoreline whose total length is 500 km, where wave of a sufficient height are available.

The potential of the wave energy is comparable with the technical potential of first stage tidal power developments designed in the UK, but its quality is much inferior to the potential of the tidal energy, as the monthly average potential value of the tidal energy is invariable and its fluctuations within this period are strictly regular and predictable in contrast to spontaneous wave energy. However, using average seasonal values, the maximum of the wave energy potential coincides with the autumn-winter period of increased energy consumption and the total number of hours of utilization per year of the wave installations is more than that at the TPPs (4000 and 2500 hours, respectively).

This gives generation of 40 TWh and corresponds to the possible annual energy yield of TPPs. But the construction of wave installations in the open sea, designed for storms, as well as the necessity to service them on rather an extensive front far from the shore, results in a high cost of 1 kWh of energy (5.6-15.5 pence’s), and this makes it impossible to compete with nuclear and tidal plants (3-4 pence). For these reasons the UK Department of Energy in 1982 took a decision not to construct large wave power stations, restricting this activity to further investigations.

The total energy potential of ocean currents is 2-2.5 times greater than tidal and is concentrated in global ocean currents near the shores of the UK, Florida, Australia, Norway, the Kurila Islands as well as in narrows and bays with high tides. Due to lower concentration of kinetic energy than in the case of use of head (at velocity of 2 m s^{-1}, 4 kW may be obtained per 1 m^2), generating units of giant dimensions may be required for the construction of full-scale electric power stations on ocean currents. So, in the USA installations of 1 GW capacity are proposed with straight-flow turbines 168 m in diameter, in UK 100 m, and in Australia 85 m.In Russia, schemes of new installations are being developed enabling the power extraction from 1 m^2 of the current cross-section to be increased from 4 to 6 kW (at a velocity of 2 m s^{-1}). With creation of a system composed of 43 underwater vertical blades 90 m high moving in a circle of 1.8 km in diameter at a velocity of 8 m s^{-1} with 160 000 m^2 cross section, a power capacity of 1 GW may be obtained.

Installation of a power set for utilization of tidal currents energy on the coast of Scotland was proposed in 1993. This power set, developed and manufactured by the firms of Nuclear Ltd. and JT Power Ltd. with participation of the National Engineering Laboratory of UK, is a double-blade turbine (similar to a wind turbine) 4 m in diameter submerged into the flow and connected to the generator enclosed in a bulb; the bulb is anchored by a cable to the sea bottom. The set capacity attains 10 kW at 2 m s^{-1} flow velocity. The generated power is transmitted by a cable to a storage battery located on a pontoon above the power set. The designers were striving for the simplest design so as to provide a prototype for numerous modules, 1 MW in capacity each. Employment of these modules on a mass scale and connection of them by underwater cables with the national power grid could meet up to 10 to 12% of the UK’s electric power demand, even at the lowest efficiency of 20%.

The designers believe that the costs of installation of such modules will be considerably less than the construction costs of traditional TPPs and the time required for their installation will be months instead of years. The prime cost of 1 kWh of electric energy from the first project was estimated as high as 10 pence but with mass production of the modules, the cost of 1 kWh might be reduced to 5 pence. However, the capital costs of this installation will be US$ 330 000, that is $ 33 000 per 1 kW, while the costs of 1 kW installed at the Severn TPP are only US$ 1500 according to the design estimates.
Tidal power plants and power stations on sea currents may be compared at most sites where tidal plants are being designed, as usually it is possible to construct a PSSC there. First of all, they have to be compared by their specific power potential - density (concentration) per 1 m of the shoreline (or more exactly - per 1 m of the installation site under consideration). Then, for example, for the Penzhinskaya TPP the figure is 1200 kW per 1 m, and for the Severn TPP - 1100 kW per 1 m, while for the most

updated PSSC it will amount only to 112 kW per 1 m. For sites with smaller basin water areas, even with high tidal ranges, this difference between the specific power potentials decreases: The Fundy TPP - 403 kW per 1 m and the Rance TPP - 730 kW per 1 m.

As the specific energy of PSSC (under favorable conditions at a velocity of 2 m s^{-1}) appears to be by an order of magnitude greater than wave energy and 3-7 times less than the energy of TPPs, the energy-economic validity of PSSC depends on the comparison of costs of their installation, defined on the basis of actual studies. Unfortunately, design studies of PSSC are not available at the present time, so it is difficult to make the comparison of TPP and PSSC costs, but there is no reason to predict a low cost for a power station on ocean currents. The erection of a set of blades - columns of tens and even hundreds of meters high, which will be able to withstand the dynamic influence of the flow; the installation of these columns on the submerged foundation and construction of the foundation itself is a complicated task, and it is difficult to assume that this complex will be simpler and cheaper than the manufacture and installation of power house caissons on the sea bed by the floating caisson method. Ice and the underwater location also create serious obstacles for the construction of PSSC.

When comparing these power stations relative to power generation it is obvious that the PSSC can use only part of the power potential of the TPP basin, depending on actual conditions of the site. For example, in the shallow-water Mezen Bay, in the TPP site, it is possible to construct a PSSC only at a section with a depth of 20-25 m and obtain the capacity of 0.8 instead of 15 GW in case of a TPP. Shifting the PSSC to a deeper part of the bay seems to be not expedient because of the decrease of velocities. The same picture may be observed at other sites where powerful TPPs are under design. It is obvious that at the present level of design studies in those sites where large TPPs are being designed and are proposed for construction, power stations on ocean currents cannot compete with them. Electric power stations harnessing ocean currents on powerful streams (the Gulf Stream, Kuroshio, etc.) may be efficient far from the bays, where the TPPs cannot be constructed, or in narrow straits with high flow velocities. Accordingly, from all kinds of ocean energy, tidal energy is the most practical for the near future.

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Biographical Sketches

Lev B. Bernshtein was born on December 21, 1911, Nizhii Novgorod, Russia/

1939 – Graduated from Moscow Engineering Construction Institute.

1973 – Doctor of Technical Science (Thesis: On utilization of tidal power and construction of the pilot Kislaya Guba tidal plant).

1939-1999 – Chief Engineer of tidal power plant projects, Design, Survey and Scientific Research Institute «Hydroproject».

Author of more than 100 scientific papers and 8 monographs.

Main activities: Creator of a Russian school of tidal energy usage; author of the first Kislaya Guba tidal power plant; developer of lightened structure for low-head hydropower plants; leader in using of bulb units at hydropower projects.

Honorary member of the Academy of Water Economical Sciences, member of International Power Academy/

He died (1999).

Igor N Usachev was born on July 4, 1932, Moscow, USSR

1957 – Graduated from the Moscow Power Engineering Institute.

1973 – Candidate of Technical Sciences (Thesis Investigations of very high frost concrete and fine-wall reinforced concrete hydraulic structures at the North.

1957 – up to now – engineer, chief engineer of the projects, Director of Laboratory and Head of Department, Design, Survey and Scientific Research Institute «Hydroproject».

1963-1984 – Chief of Group on Working Designing and studies of Hydroproject, Kislaya Guba tidal power plant/

Author of more than 400 scientific papers and 7 monographs.

Main activities: mastering tidal energy; introduction of floating techniques in erecting of hydropower projects; development of long-lasting marine construction materials; electro-chemical and biological corrosion protection.

Member of Scientific Council on Biological Damages of the Russian Academy of Sciences.