HISTORICAL SKETCH, PERSPECTIVE AND CLASSIFICATION OF TPP SCHEMES

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Summary

Many examples of tidal energy utilization are known starting from the 11th century, when on the coastal areas in Europe and later in America people built dams for separation small bays from the sea where wheels were installed, which worked during the outgoing tide at dewatering of bays, separated from the sea.

These first TPPs were used as tidal mills, for water supply, to drive saw frames.

Starting from the middle of the 19th century a great number of proposals and projects on tidal energy utilization began to appear.

The main obstacle for TPP construction turned out to be daily non-uniformity of tide. Engineers worked 200 years at elimination of this non-uniformity, often dividing the bay into two or three and more basins, subsequently putting them into operation.

TPP projects considered single-pool single-action (outgoing tide) and double-action (incoming tide) schemes with additional pumping effect. As a result, the conclusion was made to the benefit of single-pool scheme when compared to double-pool scheme and to the benefit of double-action operation as compared to the single-action one in ecological aspect.

At present when actually all the generating installations are interconnected, the optimal model is a single- pool single- or double-action TPP, operating in a large power system with hydropower regulating capabilities.

1. Historical Perspective of Utilization of Tidal Power

The tides as a source of energy were exploited as early as the Middle Ages, when the phenomenon of tides was not yet understood. For example, tidal power was used in the coastal areas of Andalusia, Gaullia, UK, Canada, and the White Sea to drive many water mills. Judging by the vestiges that have survived and by a few tidal mills still in operation, tidal mills were erected on small bays communicating with the sea by narrow ducts, or in river estuaries. Their basins were separated from the sea by dams equipped with sluice gates or flap gates. The gates were opened automatically by the tidal current during the incoming tide and closed during the outgoing tide. The water thus trapped was used to drive large water wheels, up to 6 m in diameter. In the past century, such wheels were still in use for pumping sewage in Hamburg, and in 1824 the City of London was still being supplied with drinking water by huge tide operated water wheels installed in 1580 under the arches of London Bridge, where they were in use for 250-years. There are still tidal installations driving saw frames in New England, USA.

Many other methods for direct utilization of tidal energy in a more efficient way than in the tidal mills have been suggested. Between 1856 and 1939, 280 patents dealing with this problem were registered. The number of patents for inventions of such plants has grown during recent years. The previous tidal power inventions are briefly considered below, as the new inventions are based on the same principles.

The greatest number of inventions (an example is the installation engineered by Chauvet) are of float types which transmit the tidal oscillations to drive power machines installed ashore (see Figure 1,a). However, use of even very large floats cannot lead to generation of a substantial amount of energy. A float, 1000 m^2 in area, at a water rise rate of 0.12 to 0.55 mm s^{-1}, produces an output of power from 1.5 kW to 5 kW.

In the UK, Shepard offered to replace the float with water wheels having variable-incidence blades and fixed on a vertical shaft.

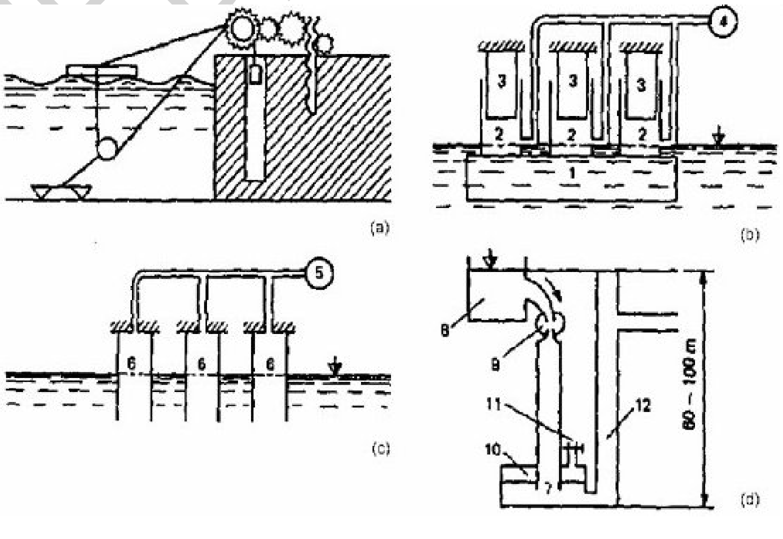

Figure 1. Diagrams of tidal power devices proposed

The tidal power was also utilized for pumping of water (Figure 1, b) from reservoir 2 to hydraulic machine 4 with the aid of float 1 and stationary cylinders (pistons) 3, or for driving pneumatic actuator 5 by compressed air from bottles 6 (Figure 1, c). The pilot installations built by Taylor in the USA utilized the tidal energy to supply water trapped in reservoir 8 communicating with the sea to the bottom of shaft 7, and also to entrain air (through ejector 9) and to compress it in chamber 10 (Figure 1, d). Then, the compressed air was conducted via pipe 11 to the mechanism. The used water was drained via pit 12.

Other suggestions were made to utilize the horizontal component of the flow velocity. Because of the relatively small amounts of specific kinetic energy per unit cross-section of the flow; this energy can be efficiently used only by installations furnished with large wheels up to 100 m and more in diameter. With water wheels having a diameter of 4-5 m, the expected power output was only 400-600 W.

The use of medium- and low-head water pressures in tidal installations employs the principle of the simplest and most efficient conventional single-pool tidal mill having its water wheels replaced with a present-day generating unit installed in the dam. The efficiency of this replacement is well illustrated by the Woodbridge tidal mill built in the 12th century, its wheels developing 11 kW. Replacing those wheels with generating units in the UK, Shepard offered to replace the float with water wheels having variable-incidence blades and fixed on a vertical shaft. Taking into account the 30000 m^2 area of the basin and its mean tidal range, would make it possible to obtain a power output of 442 kW or 40 times as much.

Naturally, utilizing tidal energy under present day conditions, when immense bays can be impounded, opens up the prospect of obtaining power outputs measured in hundreds of thousands and millions of kilowatts. However, the way from the 11 kW tidal mill in Woodbridge to powerful tidal systems has turned out to be very difficult.

The first and major hindrance to the designers of TPPs consisted in the diurnal inequality and discontinuity of tidal energy. While this is of no importance for simple tidal installations, since they can operate regardless of the solar hour, and their attendant personnel, consisting of only a few persons, can adapt their activity to the tidal cycles, the loads of a powerful TPP cannot be satisfied by such an inequality.

The result of tidal energy inequality can be seen from an example dealing with the design of the Quoddy TPP, USA. In the course of the quadratures period its power capacity increases during the operation time from 30 to 70 MW and then again decreases to 30 MW. In the course of spring tides, the plant power capacity increases from 30 to 130 MW and again decreases to 30 MW. The operation time (during the period of mean tides) is 7 hours and 3 min. The interval for equalizing the levels and building up the operating head is 5 hours and 23 min. Also note that the operating cycles of the TPP are shifted every day (fall behind) by 50 min.

It took 200 years for French engineers to eliminate this inequality of tidal energy. From an artillery engineer, Belidor, who in 1737, in his description of the tidal mill in Dunkirk, outlined the methods providing a continuous supply of tidal power, to

Decoeur, Claude, Caquot, Deflour, all the authors attempted to tackle this problem by dividing the bay, impounded from the sea for the TPP, into two or three basins (double- or multi-pool scheme) and connecting these basins through the turbines in sequence to the sea, or to each other.

Most suggestions on the construction of TPPs on these and other schemes were made in France. Given below are data on the single-pool schemes that present interest from the modern standpoint, and also on the double-pool schemes, inasmuch as their previous configurations are again suggested and being developed at present.

According to the project of the Aber-Wrach TPP (France, 1924), it was expected that closing the estuary of the River Diurt would produce 4 MW with generation of 14.5 GWh per year, the intermittent energy of the TPP being used to charge the storage batteries of submarines. Yugenen’s variable rotational speed turbines were provided in the design. The construction of the TPP started in 1928, however was stopped, since the energy costs of this scheme exceeded the costs of the energy generated by a thermal power station.

The Frenaye TPP project (France, 1925) was proposed by Vigour in 1911. It was shown in the modified project of 1925 that tidal energy could be utilized more efficiently in the single-pool double-action scheme. The project actually realized the idea of the variable rotational speed operation of the turbines used to generate DC power into the power system over a transmission line up to 900 km in length. A special pumped storage power plant to accumulate the TPP excess energy was also designed.

The projects of these power plants are also interesting because they featured the powerhouse of the throughway type which allows the double-action operation of the TPP with a vertical turbine. A design of the same type but with a unique layout was offered in two versions of the Kislaya Guba TPP scheme in 1939-1940 in USSR, in which it was proposed to install three vertical generating units 456 kW each.

A unique approach was suggested for the first project of Severn TPP (UK, 1916). The same approach was suggested in the project of the San-Jose TPP (Argentina, 1928). It was proposed to use Francis turbines with a set of specific deflectors situated under the turbine to cause and utilize the ejection effect. Total 370 such generating units (in the TPP power house 5.5 km long) with different diameters (up to 10 m) and power capacity, as dictated by the depth were supposed to be installed.

A modified layout of a conventional hydroelectric power plant power house with vertical generating units was offered in the project of the Lumbovskaya TPP (USSR, 1941). This modification was the use of the throughway water passage under the generating unit. A unique throughway design with vertical generating units and a siphon turbine chamber was proposed in the project of the Quoddy TPP (USA, 1935). This scheme with horizontal generating units was implemented by the Husum TPP (Germany, 1940) that was dismantled before the Second World War.

In 1938, Defour proposed a three-pool TPP design, according to which the three pools were in turn connected to the TPP powerhouse by means of a special dam having sluices for communication of the head and tail races. This project could implement the most perfect of the prewar three-pool cycles of Caquot and Defour (1937), which could control the TPP power output, following the load curve.

In addition to this TPP, it was proposed to implement double-pool schemes with different cycles on the northern coasts. Many of these schemes were associated with the estuary of the Rance River. The reappearance of these double-pool schemes in the projects of today is described below (in particular, for the Severn Estuary).

Before the Second World War and then after it, new projects appeared in the USA, UK, and France. The first commercial TPP at La Rance, France, was constructed and commissioned in 1967. At the opening of this TPP President de Gaulle called the TPP of Rance "an outstanding structure of the century". But, the Minister of Industry who took the floor after the President stated that the subsequent plants for developing the French power industry would not envisage the construction of TPPs and that priority would be given to nuclear power plants. This was because of the high costs of the Rance TPP construction: the cost of 1 kW was 2.5 times that of a comparable river hydroelectric station of Gerstkheim (2000 and 800 French francs, respectively).

As a result of this and also from the unsuccessful experiment of the started and then abandoned construction of the Quoddy TPP, called at that time an "economic folly", a number of authoritative specialists raised objections to the construction of TPPs. They stated that the TPP total power capacity is insignificant, and use of tidal power is difficult because of the cyclic and intermittent nature of tidal energy as well as its high costs.

However despite this reluctance the problem still remained. Renewed interest appeared not only because of the changing economic situation (firstly the increase of oil prices) but also thanks to the role of scientists-leaders, concerned with the problem. Paying homage to a number of pioneers for their activity it is necessary to point out that the list of leaders should be headed by the French scientist R.Gibrat, together with the whole team of specialists, whose efforts resulted in the creation of the theory of cycles and the Rance TPP. In Canada R.H.Clark, the engineer being at the head of a number of committees on tidal power utilization, together with his colleagues worked out the designs of powerful Cumberland and Cobequid TPPs.

In UK in the 1970s in the designing of TPPs a return was made to single-basin schemes, described by Prof. E.M.Wilson in journal "Water Power" (1964), and developed by him in all his subsequent studies up to the present time.

In Korea the leader of the tidal power projects design team for many years has been Won-Oh Song.

In Russia a large team of specialists headed by the author of this Article worked on this problem. Exactly as a result of the activity of this group of enthusiasts a favorable economic situation was realized and the scientific-technical potential was created in structures of the Rance TPP, then Kislaya Guba (Russia, 1988), Annapolis (Canada,

1984) and Jiangxia (China, 1988). The designing of powerful tidal power schemes is under way now in a number of countries.

This has aroused a new wave of interest in tidal energy, involving new investigations and publications.

The pre-war publications described the phenomenon in general and proposed schemes of small TPPs operating on the principle of tidal mills. In 1961, L.B.Bernshtein published a monograph where, as well as stating the difficulties of mastering tidal power, which is intermittent within 24 hours and varies during a month's period, he showed its concealed advantages and described how the difficulties could be overcome making tidal energy an important component of a power system. In contrast to small multi-basin plants that were designed during preceding years to supply electric power to coastal settlements, it was proposed to capture tidal energy by barraging large sea bays in the form created by nature, in single-basin plants. These would generate maximum amounts of energy at minimum costs. Further the energy would be directed into power system pools covering countries and even continents. Thus, the pulsating, intermittent, but renewable tidal energy would combine with the energy of other power stations mutually improving the operation of each other. In this way, tidal energy becomes controllable and, being transformed from the moon's to the sun's cycle, is directed to the electrical power systems partially at the peak and in part for base load, allowing fossil fuels to be saved.

In this book the assessments were made of the probable use of the tidal energy capacity (0.7 TW), being a fairly moderate fraction of the river power potential capacity (4 TW), and much less than unlimited nuclear power. Some countries, whose coasts are washed by seas with high tides, were taken as examples to show the potential energy that could be obtained by these proposals.

The book also offered the caisson (floating) techniques of constructing TPPs and the relevant structural design of the plants that make it possible to reduce their costs drastically. Many experts regarded this book as a manual providing foundations for design of tidal power plants.

In 1956 in France the International Congress "Sea Energy" was held where theoretical and engineering issues concerning tidal power design and mainly the Rance Project were discussed. In 1958 "hydraulic days" were held also in Aix-en-Provence France where the hydraulic turbines for the TPP were considered. The whole avalanche of publications devoted to investigations, designing and construction of the Rance appeared in 1958-1970 in the world scientific-technical press and mainly in France.

In 1961-1983 the author's publications describing the evolution of the horizontal axial units applicable to the TPP were published in the USSR.

Valuable information is included in the transactions of the Conference in Halifax (Canada, 1972), transactions of the Colston Symposium (1979) and Cambridge Symposium by BHRA, 1981, transaction of the Brighton Symposium, 1986, 1988 and London Conference on Tidal Energy, 1989, 1992.

In 1978, in Seoul the International Symposium on Korea Tidal Power was held, at which great attention was paid to application of the Straflo turbine.

Following the commissioning in 1980 the first hydropower set of the Jiangxia TPP in China, a number of reports on this plant and on experience in the plant operation have been published.

The book “Tidal Energy” by R.H.Charlier was published in 1982; some chapters devoted to tidal power development are available in the book “non-traditional sources of energy” by R.N.Taylor, published in UK in 1983; a session of the Hydrotechnical Society devoted to the 20th anniversary of the Rance Project commissioning was held in France in 1986.

In 1987 Prof. B.Gerwick published a book entitled “Construction of Offshore Structures”. Prof. Gerwick - a prominent expert in this field - had generalized and analyzed in this book the world experience in designing and construction of floating platforms, which had been taken into consideration in designing of floating caissons for TPPs.

Recently a number of international conferences and symposia devoted to tidal energy were convoked (Delhi 1988, Brighton 1989, Honolulu 1989, Halifax 1991, London 1992 a.o.)

In 1991, A.C.Baker published the monograph “Tidal Power”, where he described some oceanographic and technical aspects associated with designing tidal plants (dam, turbine, economy) and where he gave brief information on some sites and tidal power projects.

In the monograph “Tidal Power Plants” (edited by L.B.Bernshtein) published in Russia in 1987 various aspects relevant to tidal power utilization were analyzed: power engineering (optimization of the TPP operation in a power system), oceanological (effects of TPPs on tides), equipment (bulb and straight flow hydrogenerating units), civil engineering (floating constructions and their erection techniques).

A detailed description and analysis of construction of the Rance Project and the experience of its operation has topical importance for further designing of TPPs, since for the Rance TPP a new solution to the problem was realized through unique bulb units. An analysis of the Kislaya Guba TPP is also given which demonstrated a new approach to tidal power plants construction avoiding erecting the cofferdams, fencing the tidal plant pit in the sea, reducing by 25-33% the construction cost of the proposed TPPs in Russia and abroad.

Large-scale models of floating structures described in the 1987 publication, were realized on the Dnieper River and in St. Petersburg as the prototype for transition from small Kislaya Guba TPP to powerful tidal projects and were continued in the USA in 1991 by the design of Love hydroelectric station.

As a result of these studies and design developments, the technical substantiation of the largest TPPs designs (Severn, Mersey, Cumberland, Cobequid, Garolim, Tugur) was completed and the International Symposium on Tidal Power Plants (Murmansk, 1991) declared that at present the technology of generating the tidal energy was successfully proved on three continents and was based on up to date technologies and equipment.

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Biographical Sketch

Lev B. Bernshtein

Born 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).