TIDAL ENERGY

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Contents

Summary

This chapter presents an overview of the world’s tidal energy situation. The program “New energy ideas for the 21st century”, which was adopted on the initiative of Russian specialists at the first international conference on “Power generation and society”, and the sixth meeting of the International Fuel and Power Association, points out that fundamental support should be provided to continuous growth of the production and demand for pure and renewable energy sources, which will occupy the leading position on the list of important energy resources by the middle of the 21st century. It is understood that the renewable, ecologically safe and economically justified energy of marine tides is primary among these sources.

In the 1990s the potential of tidal energy has been evaluated in all countries, whose shores are washed by the world’s oceans; the most promising regions for the installation of power plants have been ascertained, and procedures developed for utilization of the power generated by tidal power plants in power systems; methods have been approved for the building of these structures under open-ocean conditions; and, finally several TPP, which demonstrate the high multisided economic effectiveness of the use of this form of renewable energy, have been constructed in various regions.

1. Tidal Range

The tidal range can vary significantly depending upon the position of the site on the globe, the coastal configuration and bathymetry. Thus it can be just few centimeters in the land-locked seas, such as the Black Sea, the Mediterranean Sea, etc., and up to many meters at the funnel-shaped bays open toward the ocean. The highest tide in the world with a range of 17.3 m is observed at the head of such a bay named Fundy in Canada. The highest tides are also in the Severn Estuary in the UK (14.5 m), at the port of Granville in France (14.7 m) and at Puerto Rio Gallegos in Argentina (13.3 m). The highest tides in Russia can be observed in the Bay of Mezen of the White Sea, in the Penzhinskaya Guba of the Sea of Okhotsk, at Vodopadny Cape (13.4 m) and in the estuary of the Kuloi River (10 m).

During each lunar day two tidal rises and two falls usually happen, i.e. with a period of approximately 12 hours and 24 minutes (semidiurnal tides) or only one high and one low tide in each 24 hours 48 minutes (diurnal tides). The actual tidal oscillations are in most of the cases a combination of these two types and are named after the one that substantially prevails over the other. The resultant tide is called mixed tide. The highest level reached by the sea in any of the tidal periods is called high water (HW) and the lowest low water (LW). The tidal range *A* is the difference in the height of the water between low and high tides. It may be characterized by the height of the high or low water with respect to the mean sea level called the tidal amplitude, *A*/2 (Figure 1).

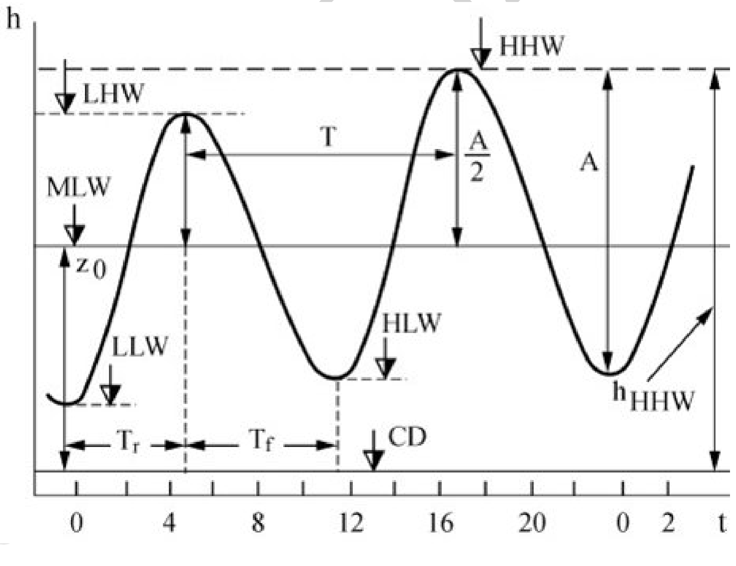

Figure 1: Characteristics of tide

These characteristics may significantly vary in time at a given site. Over the interval of 14.7 days, which is a half of the lunar month, the most noticeable changes happen. During this period the amplitude varies from its maximum to minimum and again to maximum. These extreme values are also varying in magnitude. In the course semidiurnal tides the maximum amplitudes take place at New Moon or Full Moon (spring tides) while the minimum amplitudes are observed about the time of the first and third quarters of the New Moon (neap tides). In the course of diurnal tides, the maximum amplitudes take place at the extreme declinations of the Moon (tropic tides), and the minimum at the zero declination (equatorial tides). The amplitude of the resultant tide reaches its maximum magnitude when the tropic tides are in phase with the spring tides.

The tide generating force resulting from the gravitational interaction between the Earth, the Moon and the Sun causes the periodic rises and falls in the level of water in the world's oceans and tidal currents. Due to the rotation of the Earth-Moon system around their common center of gravity, the tide generating force of the Moon at a given point of the Earth's surface is determined as the difference between the local gravitation attraction of the Moon and the centrifugal force.

Another type of tides is that of tides caused by the Sun. They occur on the same principles as the lunar tides, but are smaller by a factor of 2.17 because of the much longer distance between the Earth and the Sun. The simple semidiurnal periodicity of tidal oscillations is affected by three basic factors, i.e. a variable declination of the tide-generating celestial bodies (the Moon and the Sun) with respect to the Earth's equatorial plane, changes in their relative positions with reference to the Earth, and finally, changes in their respective distances from the earth. The resulting effect is called inequalities of tide caused by differences in the heights and times at which the high and low waters take place. The difference in two adjacent high and low waters during 24 hours and differing times of fall and rise is known as diurnal inequality.

The parallax inequality or monthly inequality is caused by the variation of the Earth's distance from the Moon, since the Moon goes around the Earth in an elliptical path. The resulting tide increases when the Moon is in its perigee, i.e. at the distance of 57 earth radii. And accordingly the tide decreases when the Moon is in its apogee, i.e. at the distance of 63.7 earth radii. Such variation of the tidal range takes place every 27.55 days.

2. The Energy of Ocean Tides

The energy of ocean tides is the result of the tide generating forces. Part of it can be lost due to the dissipation resulting from the tidal friction forces and also by the power interchange between the Earth and its atmosphere. The energy may change from the kinetic to the potential form and vice versa in the course of tidal motions. Because the tidal motions have wave nature, wave energy transfer may take place within seas and oceans.

The world ocean has an energy balanced state as well as its separate parts, i.e. seas, oceans, etc. The following major factors determine tidal energy: work of tide generating forces, energy dissipation by friction forces, and power interchange between the basin and the solid parts of the Earth. The quantitative estimates of the energy flows are equal to 2.4 TW.

It is difficult to provide preliminary quantitative estimation of the energy derived from the tidal process with the help of an actual TPP even in ideal conditions. The reason is that the construction of TPP and operation of its generating units have an effect on the structure of the tidal wave, which leads to the transformation of the tidal regime. Under such conditions, however, simplified formulas of estimations are being used, for a number of cases mentioned below. These formulas can be used at the preliminary design stages. One of the widely used formulas is Bernshtein formula given in the following. It can be used to define the annual potential energy of the tidal basin E in kWh.

$$E = 1.97 \times 10^6 \times A_m^2 \times S \qquad (1)$$

where A_m - mean tidal range, S - Area of the tidal basin, km^2

This formula can be used to estimate the energy potential of the basin when the tide has a regular semidiurnal origin. This is typical for the majority of coastal sites where TPP are constructed.

If the tide is of the mixed nature, the energy potential of the tidal basin can be estimated by the following formula:

$$E = 1.97 \times 0.5 \times 10^6 \times A_m^2 \times S \times \left(1 + \frac{4-D}{4}\right) \qquad (2)$$

In this formula D changes from 4 (24 hours tide) to 0 (12 hours tide).

3. Main Positive Features of Tidal Energy

The period of tidal inequality (when tidal fluctuations change from the spring tide to the neap tide state) is represented by the synodical lunar month. During this period main tide generating factors go through all their typical phases (see Figure 2).

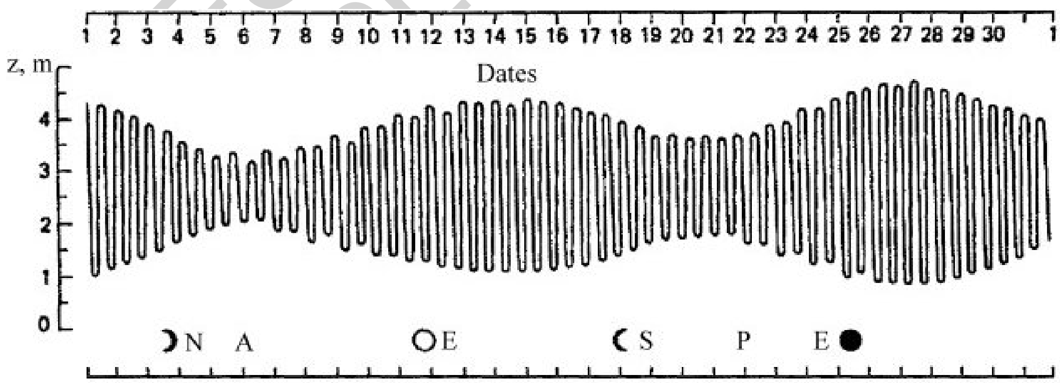

Figure 2: One-month diagram for a regular semidiurnal tide (Sosnovets island, White Sea):
○ full moon; ●- new moon; E - Moon at the equator; S - Moon in southern declination; N - Moon in northern declination; A - Moon at apogee; P - Moon at perigee

These laws of tidal variations within one month are caused by the movement of planets and speak for invariability of the complete monthly cycle for all lunar months of the year. As the tidal wave is a function of its amplitude, the tidal range variations illustrate fluctuations of tidal energy. The graph analysis shows that the mean lunar month tidal energy remains unchanged (like the mean tidal range) for any month of any year. This is the main advantage of the tidal energy, i.e. the invariability of the monthly average power annually and in series of several years. Thus tidal energy can be compared with river energy.

4. Projects of TPP

The tidal energy was first discovered back in the Middle Ages. It was used in water mills in coastal areas of the UK, France and Canada. The first tidal mills were built on small bays near the sea or in the river estuaries. Dams equipped with slice gates or flap gates were used to separate their basins from the sea. The gates were opened and closed automatically during incoming and outgoing tide. The trapped water was used to drive big water wheels, which reached 6 m in diameter. In the 19th century such wheels were used in Germany for pumping sewage in Hamburg. In England the City of London was supplied with water using water wheels installed under the London Bridge. There were also other schemes regarding usage of tidal energy and in the period between 1856 and 1939 over 280 patents were registered dealing with this problem. The main problem for the construction of TPPs is the diurnal inequality and discontinuity of tidal energy. Thus it took over 200 years for French engineers to eliminate such inequality. All engineers working on this problem (Belidor, Decoeur, Claude, Caquot, Defour) tried to solve it by dividing the bay, separated from the sea for the TPP, into several basins connected to the sea or to each other with turbines.

There are still discussions regarding TPP with several basins. However a long history of the pioneer TPP Rance in France and the Kislaya Guba TPP in Russia proved the advantage of the one basin TPP scheme and inclusion of TPPs into main energy system. Ten TPP are operating in the world today: the commercial Rance plant in France (240 MW, placed in service in 1967), and experimental plants - Kislaya Guba in Russia (400 kW, 1968), seven TPP in China (total capacity of 10 MW, 1971-1980), and the Annapolis plant in Canada (20 MW, 1985). In the 1990s, designs have been developed for large-scale TPP in England - Severn (7.2 GW) and Mersey (0.7 GW), and in Canada - Cumberland (1.15 GW) and Quebecuid (4.08 GW); design work is currently underway on TPP in South Korea and Australia. The building of the Rance and the Kislaya Guba TPPs signaled a new era in the use of tidal energy, making it possible to implement its practical use in power systems by daytime transformation of the moon's energy. The 30-year operation of these TPPs has demonstrated the economic efficiency of tidal energy and the ecological safety of TPP.

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Biographical Sketch

Igor N Usachev was born in 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-living marine construction materials; electro-chemical and biological corrosion protection.

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