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THERMOELECTRICITY AND OCEAN

The prospects of using thermoelectric generators for ocean thermal energy conversion are discussed. It is shown that thermoelectric method of power conversion is capable of assuring competitive technical and economic performance as compared to traditional systems of ocean thermal station (OTEC).

Key words: thermoelectric generator, ocean thermal energy.

Introduction

The global ocean covers more than 70 % of the earth surface. In fact, it is a huge natural accumulator of solar energy the absorption of which creates temperature gradient between the surface and deep water layers. In tropical latitudes this difference reaches 20 °C (Fig. 1). By the existing estimates, from the ocean surface restricted by a square of one degree of latitude and longitude, one can obtain 100 mlrd kW-hours of thermal energy per year. That is, it is almost a boundless source of thermal energy that can be converted into electric energy. However, this resource is hard to be exploited, since currently existing technologies of ocean thermal energy use have not yet reached the commercial level.

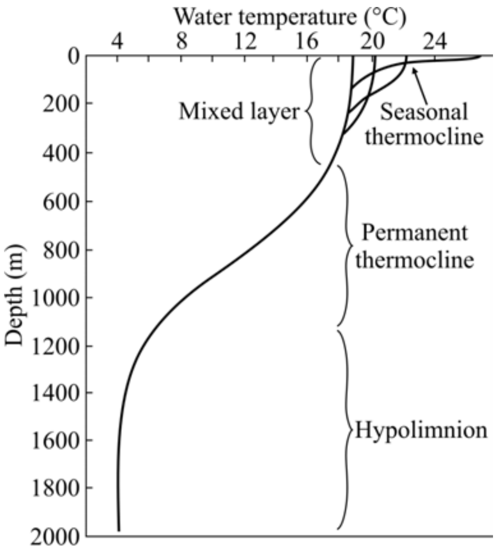

Fig. 1. Temperature distribution within the ocean column.

Starting from the 70-s of the last century, investigations have been pursued to use ocean thermal energy mostly in two directions, namely to supply energy to island consumers and for power supply to self-contained systems (navigational and oceanological buoys, etc.).

A series of implemented pilot projects [1, 2] confirm principal opportunity of achieving acceptable technical and economic performance of OTEC, but this technology does not find industrial application so far. Considerable attention to studies of this problem is paid to the Asia-Pacific region. There are 15 research centres in Japan that are equipped with systems of deep sea water delivery of volume from 500 to 13000 tons per day [3]. The largest of them, “Kumejima” project [4] stipulates creation of a sustained development model for small islands of Okinawa prefecture (Japan) which is based on the use of deep sea water for ecologically clean energy, agricultural and aquaculture technologies. The project is based on cold sea water delivery system providing for supply of 13 thousand tons per day of water with temperature 6...9 °C. This resource is used for room air conditioning systems, product cooling and in aquaculture. In June 2013, a project of 50 kW demonstrational OTEC was put into operation on the island (Fig. 2) [5].

Fig. 2. 50 kW demonstrational OTEC on Kumejima Island [5].

The project was developed by Institute of Ocean Energy of Saga University and company Xenesys in cooperation with Natural Energy Laboratory of Hawaii, NELHA. In the USA, the leading company in the field of investigations on ocean energy problems is Lockheed Martin Corp., developing the project of OTEC of power 10 MW [6]. Another big centre of research on OTEC problems is Taiwan.

The prospects of using TEG for ocean thermal energy conversion

Modern OTEC projects focus on the use of steam-power cycle with a low-boiling refrigerant. The drawback of this technology is high metal consumption and essential dependence of economic figures on the scale factor, namely minimum power level that assures acceptable economic performance is 50 MW (Fig. 3).

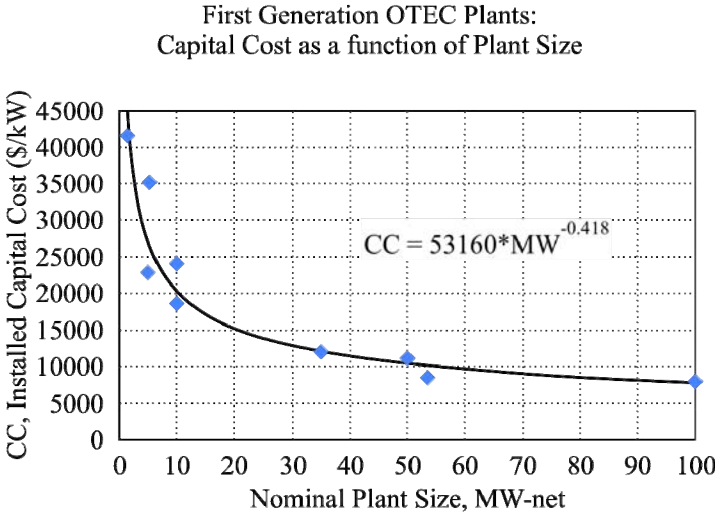

Fig. 3. Relative capital cost $US/kW versus OTEC size [1].

On evidence derived from [1], the cost of electric energy of 1 MW OTEC is 0.7 – 0.9 $US/kW-h, and for 100 MW OTEC – 0.12 $US/kW-h (Fig. 4). The latter figure can be already considered as competitive as compared to the cost of electric energy from traditional sources, but implementation of similar projects is problematic because of the necessity of big investments (on the level of

1 mlrd $US) under conditions of ill defined risks. At the same time, the experience of introduction of modern conversion systems of renewable power sources (photoelectric converters, wind generators) shows that their extensive use, despite the high cost of electric energy, became possible due to the use of low power systems (1 – 100 kW) and the use of special feed-in tariffs assuring high profitability of using similar systems. Unfortunately, for a classical OTEC system with a steam-power cycle such a way is impossible due to scale restrictions.

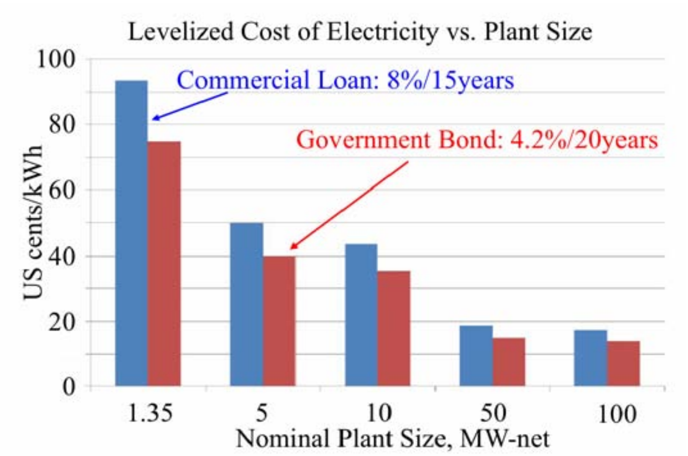

Fig. 4. The cost of electricity $US/kW-h versus OTEC size [1].

In this respect, thermoelectric method of thermal energy conversion offers certain advantages, while in the operating temperature range of OTEC the efficiency of TEG is practically the same as the efficiency of steam-power cycle (both have the efficiency 1 %). First of all, TEG are almost insensitive to scale factor, that is, economic parameters of ocean thermoelectric generator (OTEG) of 1 kW scale are practically not different from OTEG of megawatt scale which makes its possible to bring OTEG to commercial level in kilowatt power range.

An additional advantage of OTEG is a simpler design, absence of low-boiling refrigerants (as a rule, toxic), and, respectively, much higher reliability and self-sufficiency. Similar to OTEC with steam turbine generator, OTEG system includes pipelines of cold and hot water, heat exchangers, pumps, as well as thermoelectric converter and inverter. Design of a heat exchange-type TEG proposed in [7] allows combining in one unit the heat exchangers of the hot and cold heat carrier, which reduces considerably materials consumption and the dimensions of OTEC. For comparison, 50 kW OTEG will have approximately the same dimensions as condenser unit OTEC-50 (shown in the right bottom angle in Fig. 2). Estimates of electric energy cost of 100 kW power OTEG [8] confirm the possibility of reaching quite competitive level of electric energy cost (0.10 $US/kW-h), comparable to the cost of energy from conventional energy sources and unattainable for traditional OTEC schematic. This opens up the possibilities of creating 1...1000 kW OTEG for commercial use for the purpose of reliable electric energy supply to numerous independent consumers.

OTEG + “Solar pond” = OSTEG

Another schematic of using sea water potential with the help of thermoelectricity is a combination of OTEG schematic with “solar pond” schematic. Solar pond is a water reservoir 2 – 3 m deep filled with salt solution (Fig. 5). Due to the fact that solubility of salts in water is increased with a rise in temperature, situations are possible when solution stratification occurs, namely in the near-bottom layer the concentration (and density) of solution is increased, and in the near-surface layer it is reduced [9]. Owing to this, three pronounced zones appear in the reservoir, namely upper convective zone 0.1...0.3 m thick consisting of fresh water, gradient layer where salt concentration grows with increasing the depth, and near-bottom convective zone with maximum concentration.

Gradient layer due to suppression of natural convection has high thermal resistance (about three orders higher than the thermal resistance of fresh water).

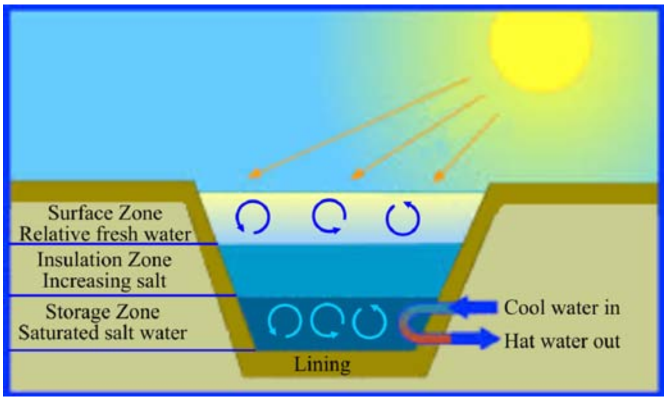

Fig. 5. "Solar pond" schematic [10].

As a result, the near-bottom layer is isolated from the surface and can accumulate the energy of solar radiation. The temperature in the near-bottom layer can reach more than 100 °C.

A combination of such thermal energy source with a powerful heat sink such as deep sea water opens up the possibilities of creation of sufficiently high-performance electric power stations. Owing to greater temperature difference, the thermoelectric generator in such a schematic has much better parameters than OTEG. The main capital expenditures account for pond construction – its cost is about 30 US/m^2 [11], which with regard to the necessary volume of heat accumulator yields 8...10 thousand $US per 1 kW of rated power of OSTEG. As compared to OTEG, the cost of schematic under study is about 30 % lower. Accordingly, the cost of electric energy with round-the-clock operation is 0.1 $US/kW-h, and in the case of using OSTEG in peak mode – 0.04 $US/kW-h [12]. The acceptable power range for OSTEG is 10 – 100 kW. The most promising application spheres are within complexes of using deep sea water similar to "Kumejima" centre on Okinawa Island.

OTEG for self-contained systems

Modern ocean is filled with thousands of various-purpose sea buoys, namely navigational, research, military, etc. that work under water in autonomous mode. The equipment of these devices requires power supply which is generally realized by means of chemical sources whose operation time is restricted.

In due time, for similar applications we proposed a thermoelectric supply with nearly unrestricted lifetime [13]. The specific feature of this device is that it can independently migrate between horizons with warm and cold water, filling the respective capacities that serve as heat accumulators. Heat flows from the hot to cold accumulator through a thermopile that generates electric current. Migration takes place at the cost of change in equipment buoyancy which occurs due to using the temperature dependence of the solubility of gases present in sea water. Later on, the principle of migration of underwater unit between water layers with different temperature for charging heat accumulators was proposed in the works of Martin Marietta Corporation, including the use of thermoelectric generator [14, 15]. However, these proposals are meant for more powerful applications, since they are based on quite energy-intensive mechanisms of assuring migration of devices.

Conclusions

The use of thermoelectric generators in applications related to ocean subject matter holds good prospects, but their practical implementation is largely dependent on the attraction of investments to scientific research.

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