Study On Electrification of Remote and Isolated Tropical Islands Using OTEC

Mahedi Hassan, Walid Bin Habib, Tahmid Rupam

2nd International Exchange and Innovation Conference on Engineering & Sciences
Kyushu University, Fukuoka, Japan
October 14th, 2016

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Walid Bin Habib, Mahedi Hassan, Tahmid Hasan Rupam
Department of Electrical and Electronic Engineering, University of Dhaka, Bangladesh
Corresponding author email: walid.habib.1994@ieee.org

Abstract: *Apart from solar and wind energy as a form of renewable energy, ocean can also be considered one as approximately 2 to 3 billion MW power can be gained from it. Covering 71% of earth's surface the ocean is the largest solar energy collector absorbing about 70% of day's solar energy. On an average day the amount of heat energy absorbed by 60 million square kilometers of the tropical sea surfaces commensurate burning of 250 billion barrels of oil and when converted to electrical energy it can limit the demand of electricity for 260 million people per day. In this study we emphasized on converting this thermal energy from the sea to electrical energy in order to provide electricity to the isolated tropical islands. This can be practically done where there is at least 20 degrees Celsius temperature difference exists between the upper and lower surface of the ocean. The conversion process involves evaporating an intermediate fluid like ammonia or direct evaporation of the sea water of upper surface and in both case cold water from lower surface performs the condensing task. Though the converted electrical energy is not sufficient for a large power plant but it can be an alternate source for the remote isolated islands where power from central grid cannot be reached. Apart from this, byproducts like pure desalinated water that can be used for pure drinking water and in agriculture sector of those islands; salt and cold water from the lower sea surface and this water can be used as industrial cooling of those islands.*
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Keywords: Renewable energy; OTEC; Tropical islands; Temperature gradient; Electrification;

1. INTRODUCTION

Finding energy sources to satisfy the world's growing demand is one of society's foremost challenges for the next half-century. This requires finding solution in renewable energy than traditional fossil fuel based energy and Ocean Thermal Energy Conversion (OTEC) is one of the potential sources that is ideally suited to provide the required thousands of megawatts of electric power with the least environmental impact. The oceans cover a little more than 70 percent of earth surface. This makes oceans the world's largest solar energy collector and energy storage system. On an average day, 60 million square kilometers of tropical seas absorb an amount of solar radiation equal in heat content to about 250 billion barrels of oil [1]. Most of the developed countries of the world have taken plans to establish renewable energy based project and OTEC is the unique among all of the energy generation technologies where there is no generation of CO_2, but it actually counteracts the effect of fossil fuel use. Therefore, it is clean, green renewable energy that doesn't involve burning fossil fuels, producing large amounts of greenhouse gases, or releasing toxic air pollution [2]. So, OTEC can be considered as a smart choice of renewable energy in Bangladesh. In this paper the purpose is to discuss the possibility of OTEC and the full research are based on the measurement of the depth level and temperature difference of the different region of Bay of Bengal and try to determine the possible geographical OTEC site selection for Bangladesh

2. OCEAN THERMAL ENERGY CONVERSION

OTEC is a marine renewable energy technology which uses the ocean's natural temperature gradient to produce electricity. Naturally, sunlight falls on oceans is strongly absorbed within a shallow mixed layer at the surface typically 35 to 100 m thick which is supposed to vary from 27° C to 29° C [1]. Beneath the layer, the more is the depth in the ocean and water of different temperature is found which is much colder than the surface. This means we have an oceanic structure where the surface waters are as hot as we can find and the deep waters are as cold as possible. This temperature difference is used in OTEC to generate electricity. The best place to find such a combination is in the tropics [3]. Basically OTEC uses the temperature gradient to drive a turbine connected to a generator which produces electricity.

2.1 Criteria for OTEC site selection

OTEC projects have been around since the 1970s (Cohen, et al., 1986) [4]. Considering the OTEC site selection criteria as mentioned in multiple papers by L.A. Vega, who is one of the key researchers and an internationally figure on this subject matter, deliberating his mentioned factors like geographical location, surface and undersea temperature, land area, population, electric energy sources, electricity demand, current availability and future electricity demand are quite important [5].

2.2 Basic process of OTEC

OTEC works on the relationship of pressure (p), temperature (t) and volume (v) of a fluid which can be expressed by the equation [6]:

$$PV/T=\text{constant}$$

2.3 Different OTEC technologies

There are basically 3 types of OTEC systems developed so far. They are: Closed-cycle OTEC System, Open-cycle OTEC system and Hybrid OTEC system.

In the closed cycle system surface water, with higher temperatures, is used to provide heat to a working fluid with a low boiling temperature, hence providing higher vapor pressure. Ammonia is usually used and is contained in large pipeline. Therefore, the system has working fluid pumped around the closed loop that has three components: a pump, turbine and heat exchanger (evaporator and condenser). Ammonia cycles around the pipe loop; picking up heat from the ocean; giving it to the power plant and returning as cooled fluid in the process [7, 8]. The vapor drives a generator that produces electricity

Open-cycle OTEC system is generally very similar to the closed-cycled system and uses the same basic components. The sea water is itself used to generate heat without any kind of intermediate fluid. Warmer surface water is introduced through a valve in a low pressure compartment and flash evaporated to convert it into steam. The vapor drives a generator and is condensed by the cold seawater pumped up from below [4].

Hybrid OTEC systems combine both the open and closed cycles [2] to produce electricity and desalinated water. The steam generated by flash evaporation is then used as heat to drive a closed cycle. First, electricity is generated in a closed cycle system as described above. Subsequently, the warm seawater discharges from the closed-cycled OTEC is flash evaporated similar to an open-cycle OTEC system, and cooled with the cold water discharge to produce fresh de-salinated water [7]. The system is shown in figure 1.

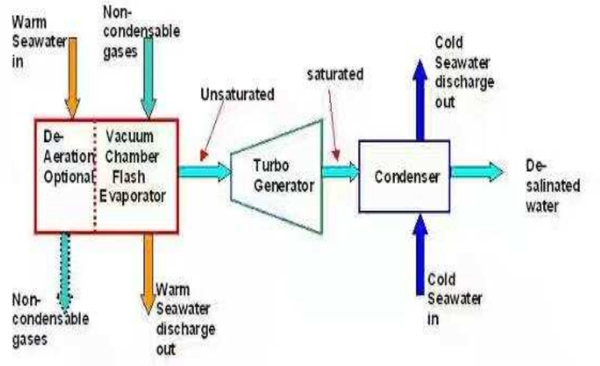

Fig. 1. Hybrid-cycle system

Besides these 3 OTEC systems, there is a subdivision of closed-cycle system called Kalina cycle OTEC where instead of pure ammonia, a mixture of water and ammonia is used as the working fluid [4].

3. EFFICIENCY OF OTEC PLANT SITES

There is a theoretical limit, $\eta_{(max)}$, to the maximum efficiency of an OTEC system in converting heat stored in the warm surface water of the tropical oceans into mechanical work. From the Carnot's equation we get the idea as mentioned below:

$$\eta_{(\max)} = \frac{T_w - T_c}{T_w},$$

Where η(max) = Carnot efficiency; TW = absolute temperature of the warm water; Tc = absolute temperature of the cold water [1].

For the ocean regions most suitable for OTEC operation, the annual average surface temperature is 26.7 to 29.4°C (80 to 85°F). Cold water at 4.4°C (40°F) or below is available at depths of about 900 m (3000 ft). Thus, the maximum OTEC thermal efficiency will be 7.5 to 8% [1].

4. GEOGRAPHICAL ANALYSIS FOR OTEC SITES

The site selections for OTEC are dependent on the temperature gradient of the surface to deep water layer of the particular location of the ocean and the temperature gradient is needed to be substantial. This is because, the efficiency of the whole system is dependent on the temperature difference between the warm tropical surfaces water to the cold deep ocean waters available at depths of about 800 to 1000 meter. The source of the thermal energy requires the temperature difference between the ocean surface and the water from 10 to 18 for cold water and 24 to 32 degree Celsius for warm water at the depth of 1000 meter. Globally speaking, regions between latitudes 20°N and 20°S are adequate for the site selection of OTEC as within this region, temperature difference between the surface and 1000-meter depth better than 22 degrees Celsius is usually available. Another important criterion for OTEC site selection is the accessibility of deep cold seawater which flows from the Polar Regions. This polar water, which represents up to 60% of all seawater, originates mainly from the Arctic for the Atlantic and North Pacific Oceans, and from the Antarctic for all other major oceans. Therefore, temperature of cold water at a given depth, approximately below 500 m, does not vary much throughout all regions of interest for OTEC. It is also a weak function of depth, with a typical gradient of 1°C per 150 m between 500 m and 1000 m. These considerations may lead to regard temperature of cold water as nearly constant, with a value of 4°C to 6°C at 1000 meter [5, 9]. From the Fig. 2 [10], it is seen that for the Bay of Bengal temperature difference between surface and deep layer of the sea water ranges from 20 degrees to 22 degrees Celsius. So it will be considered that OTEC technology is expected to be efficient in the Bay of Bengal. For the site selection of OTEC in Bangladesh, a position of Bay of Bengal which is near the Khulna region should be considered. In this region a deep crest is existed where the depth is measured nearly 1000 meter [5, 10].

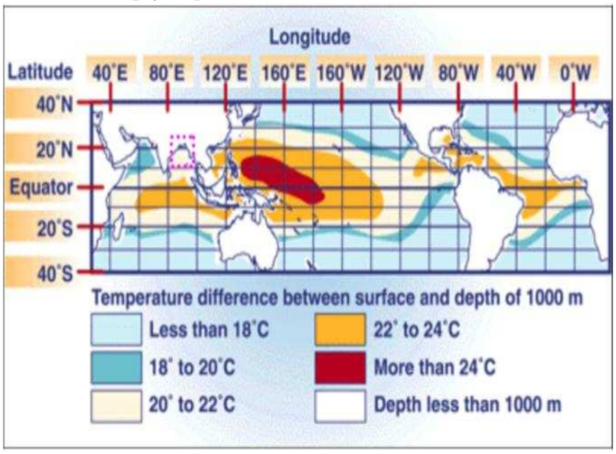

Fig. 2. Suitable location for OTEC site selection worldwide.

The weather at Khulna region is varied from maximum 36.6 degrees Celsius at summer and 12.3 degrees Celsius lowest temperature at winter. As Bangladesh lies beneath the tropic of cancer and at narrow position of the bay, every year it is affected by tropical cyclone which is one the major factor for maintenance. In Khulna region the main problem is the lack of pure drinking water for the habitants and the whole area is famous for fisheries where pure desalinated water is badly needed.

5. ENVIRONMENTAL IMPACT OF OTEC

Global warming is the major concern of the recent time and to minimize the effect of global warming, emission of Carbon-dioxide (CO_2) is needed to be controlled and in the energy generation scheme controlling carbon dioxide emission gets more priority, so use of green energy is increasing day by day. OTEC involves bringing up the mineral-rich water from the depths of the ocean and push it back to the initial depth after utilization, it contains nutrient and comprises of a different salinity level and change some natural balanced inside the ocean near the plant. It might affect the natural life habitat of some organisms. This water will promote growth of photosynthetic phytoplankton. These organisms will absorb carbon dioxide from the atmosphere into their bodies and when they will die CO_2 will be set apart in the depths of the ocean [12]. This effect is not considerably small. Each 100MW OTEC plant will cause the absorption of an amount of CO_2 equivalent to the produce by fossil fuel power plant of roughly the same capacity [13] and in this case OTEC is considered as unique and no other energy technology ever imagined can do it. Concerning the OTEC system, the release and redistribution of a huge amount of water periodically will cause localized damage to banks and near-shore marine ecosystems and some natural level changes in geological stratification, ocean salinity, oxygen and nutrient levels near the plant site. In case of any other off shore operations, there is a possibility of natural disruption of unintended fish or seabird's attraction and noise that is created from the plant might interfere with animal communication. Also, there is a fear of lubricants and anti-bio fueling chemicals entering the ocean [13, 14].

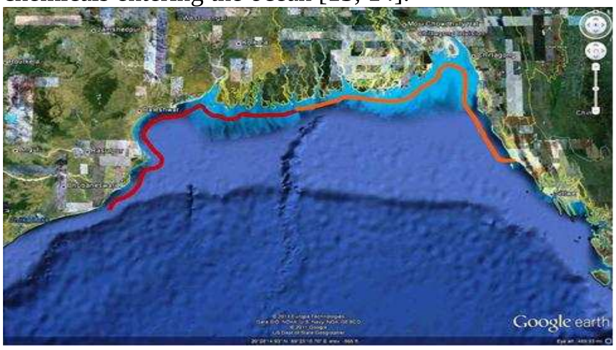

Fig. 3. OTEC Site selection for Bangladesh.

6. OBSERVATION & RESULTS

In Bangladesh, most of the regions proposed for possible OTEC sites previously inside the 200 nautical miles from the coastal areas to the Bay of Bengal are not suitable for OTEC power plant implementation as the average depth in those regions are ranging from 30m to 60m. And the temperature difference between the surface and the average depth area was not 20 to 22 degrees. However, there is a spot named Swatch of no Ground where the depth is 200m to 1200m [15]. It is located at 89.35°E to 90.10°E and 20.55°S to 21.55°S, about 30 km away from Dublarchar and 40 km from Sunarchar [16]. This is shown in Fig. 4. In this region the surface temperature in winter and summer will be close to 25 degrees and 30 degrees respectively [16]. And in 1000m depth the temperature ranges from 6.5degrees to 2.2 degrees [17]. So there will be 20 to 22degrees temperature difference throughout the year. The station is near Khulna region. In that sight a 50MW OTEC power plant will work efficiently.

This electricity can be used for electrification of remote islands in that region like Talpotti and South-Talpotti. Again electricity can be provided for hotels and other facilities in the remote places of Sundarbans (the largest mangrove forest of the world) to attract the tourists. This will eventually contribute in expanding the tourism sector of Bangladesh.

Besides these the desalinated water (byproduct of the proposed OTEC system) can be used for irrigation in these regions as the underground water is highly salinized. Apart from this, the pure desalinated water can also be used for drinking purpose and also as the raw material for bottled drinking water industry.

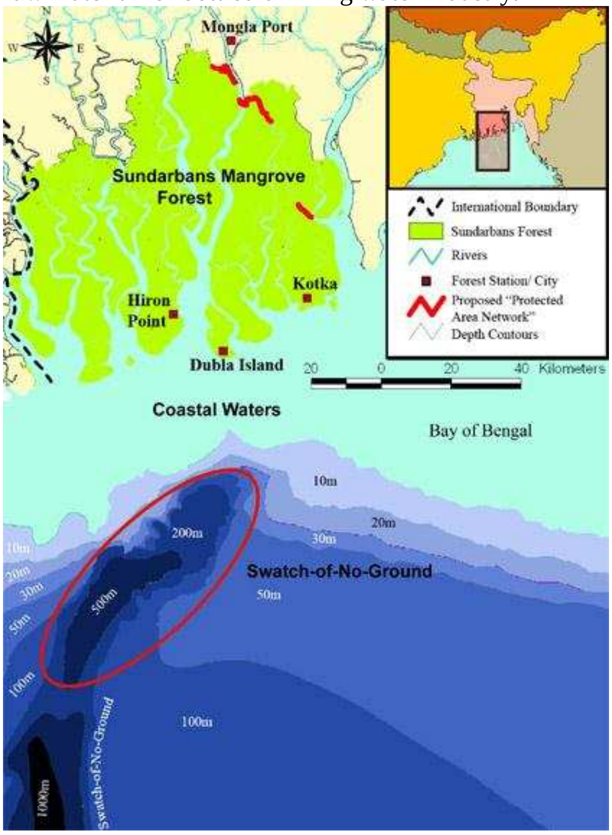

Fig. 4. Swatch-of-no-Ground shown in Bangladesh Map

7. CONCLUSION

Bangladesh being a third world developing country has a huge demand for electricity. So apart from conventional energy sources like hydro-electricity, thermal electricity producing plants other renewable energy sources should also be considered. In this regard solar energy can be a good option but its installation and maintaining cost is huge. On the contrary OTEC power plants have a large initial costing but in about five years it can compensate for its installation cost and will start making profit. Besides OTEC power plants have some useful byproducts. However, when designing an OTEC system some factors like maintain cost, pipe diameters, its distance from the shoreline etc. should be considered. By optimizing these things, the efficiency of the system can be extended to a certain amount. Again, every year several cyclones hit the coastal areas of Bangladesh. So there must be some safety measures regarding an OTEC system implementation against these kinds of natural calamities. Though OTEC power plants accounts for limited production of electricity then solar based system it is somewhat less costly to run and can surely reduce the ever growing demand for energy to a certain limit in some places. Moreover, this system can also be used for electrification of remote places and islands of the country.

8. REFERENCES

[1] William H. Avery, Chih Wu, Renewable Energy from the Ocean: A Guide to OTE, OXFORD UNIVERSITY PRESS

[2] Charlier, R.H. and J.R. Justus (1993), Ocean energies: Environmental, economic, and technological aspects of alternative power sources, Elsevier Science Publishers B.V., Amsterdam.

[3] OTEC (ocean thermal energy conversion) website: http://www.explainthatstuff.com/how-otec-works.html (Accessed 26.07.2016)

[4] IRENA Ocean Energy Technology Brief 1, International Renewable Energy Agency, June 2014

[5] L. A. Vega, "Ocean Thermal Energy Conversion (OTEC)", 2003

[6] OTEC and the pacific islands, Energy Unit, South Pacific Applied Geoscience Commission

[7] Bharathan, D. (2011), "Staging Rankine Cycles Using Ammonia for OTEC Power Production", Technical Report, National Renewable Energy Laboratory, NREL/TP5500-49121, March 2011

[8] Hammar, L., et al. (2012), "Renewable ocean energy in the Western Indian Ocean", Renewable and Sustainable Energy Reviews, Vol. 16, No. 7, pp. 4938-4950

[9] Maria Bechtel and Erik Netz "OTEC-Ocean Thermal Energy Conversion

[10] Shifur Rahman Shakil, Md. Anamul Hoque, Proposal for Introduction of Ocean Thermal Energy Conversion (OTEC) to the Energy Sector of Bangladesh, 2nd International Conference on Advances in Electrical Engineering (ICAEE 2013)

[11] V. Ramesh Babu, P. V. Sathe, V.V. R. Varadachari, Thermal Efficiencies and OTEC Potentials at some Off-Shore Sites along the Indian Coast, Mahasagar-Bulletin of the national institute of Oceanography. 16(1), 1983, 1-8

[12] L. A. Meyer-Reil and M. Koster, Entrophication of marine waters: Effects on benthic microbial communities. Marine Pollution Bulletin 41(1-6): 255-263, 2000.

[13] G. W. Boehlert and B. C. Mundy, "Vertical onshore and offshore distributional patterns of tuna larvae in relation to physical habitat features." MEPS 107:1-13,1994.

[14] L. A. Vega, "Economics of Ocean Thermal Energy Conversion (OTEC): An Update". National Marine Renewable Energy Center, University of Hawai'i.

[15] Banglapedia website: http://en.banglapedia.org/index.php?title=Swatch_of_no_Ground (accessed 16.30.8)

[16] Banglapedia website: http://en.banglapedia.org/index.php?title=Bay_of_Bengal (accessed 16.30.8)

[17] V. Ramesh Babu, P. V. Sathe AND V. V. R. Varadachari, Thermal Efficiencies and OTEC Potentials at some Off-Shore Sites along the Indian Coast, Mahasagar-Bulletin of the national institute of Oceanography. 16(1), 1983, 1-8