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Thermal power plant efficiency enhancement with Ocean Thermal Energy Conversion

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HIGHLIGHTS

- An Ocean Thermal Energy Conversion hybrid plant was designed.
- The waste heat of a power plant was delivered as an OTEC heat source.
- The effect of size and operating conditions on plant efficiency were studied.
- The OTEC implementation in a Chilean thermal power plant was evaluated.
- The net efficiency of the thermal power plant was increased by 1.3%.

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ABSTRACT

In addition to greenhouse gas emissions, coastal thermal power plants would gain further opposition due to their heat rejection distressing the local ecosystem. Therefore, these plants need to enhance their thermal efficiency while reducing their environmental offense. In this study, a hybrid plant based on the principle of Ocean Thermal Energy Conversion was coupled to a 740 MW coal-fired power plant project located at latitude 28°S where the surface to deepwater temperature difference would not suffice for regular OTEC plants. This paper presents the thermodynamical model to assess the overall efficiency gained by adopting an ammonia Rankine cycle plus a desalinating unit, heated by the power plant condenser discharge and refrigerated by cold deep seawater. The simulation allowed us to optimize a system that would finally enhance the plant power output by 25–37 MW, depending on the season, without added emissions while reducing dramatically the water temperature at discharge and also desalinating up to 5.8 million tons per year. The supplemental equipment was sized and the specific emissions reduction was estimated. We believe that this approach would improve the acceptability of thermal and nuclear power plant projects regardless of the plant location.

1. Introduction

Primary energy production exceeded 500 Exajoules in 2011, 80% of which corresponded to fossil fuels. Similarly, electricity generation relied on those fuels with 41% coal, 21% natural gas and 5% oil [1]. Nuclear power came second with about 13% and the remaining was produced with renewable energy forms dominated by hydro power.

The major problem with fossil fuel reliance is the environmental damage associated with the transformation processes to other energy forms. Fossil fuel combustion emits carbon dioxide (CO_2) that is considered to cause global climate perturbations, and other products (SO_x, NO_x, PM) that cause local impacts.

An environmental impact with less public attention is also present in coal and nuclear power stations. These plants require a cooling medium to release their waste heat. They are cooled by air, typically by installing cooling towers, or water. Most plants that use seawater as a heat sink are located near the coast demanding a seawater flow of 2–3 m^3 per minute per MW, depending on inlet conditions, to extract the waste heat (almost two thirds of the heat produced by combustion or nuclear fission) from the station, increasing the water temperature at discharge. Even without changes in seawater composition, such temperature change results in an adverse environmental impact to the local ecosystem, known as thermal pollution. This rise in water temperature alters the biological, physical and chemical state of the water body and can cause physiological changes in marine organisms [2]. Various

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Fig. 1. Sagar Shakthi OTEC plant in India.

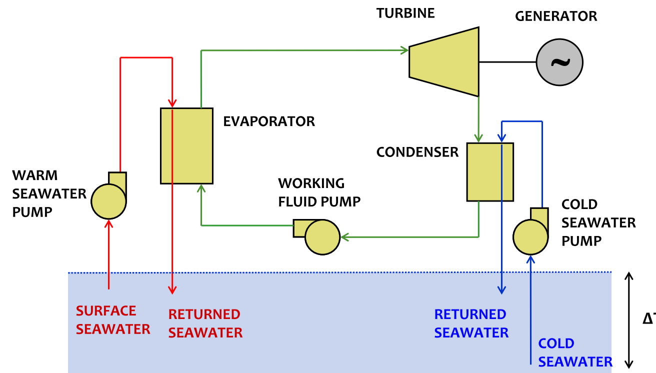

Fig. 3. Closed OTEC cycle.

studies have evaluated the impact of thermal discharges on phytoplankton which are the main primary nutrient producers supporting the coastal marine food chain, that found productivity losses from mortality increase and biodiversity reduction [3–6].

This paper discussed the feasibility of implementing a coupled Ocean Thermal Energy Conversion (OTEC) power plant and desalination system to increase the thermal efficiency of a coal or nuclear power unit while reducing its thermal impact at discharge. The proposed system makes use of the residual energy of the plant, and returns the seawater flow at a temperature similar to that of sea surface. The aim of the study was to evaluate the feasibility of efficiency enhancement of a coal-fired power plant. The OTEC system was simulated to the 740 MW Punta Alcalde power plant project, a pulverized coal-fired station to be located in the northern region of Chile (latitude 28°S).

Thermal power plants have a high participation in the Chilean interconnected systems, with more than 61% of electricity generation and 65% of its installed capacity. Most of these power stations are located on the coast, using seawater as cooling medium. The evolution of alternatives and the difficulty in adopting other energy sources on the system suggest that the thermal capacity will continue to grow and will play a key role in the future. Sixty two percent of the projects under construction are thermal power stations, almost all of which are coal-fired plants [7].

2. Ocean Thermal Energy Conversion (OTEC)

Ocean Thermal Energy Conversion (OTEC) is a technology to generate electricity using as a heat source the thermal energy stored in the sea, in which a Rankine cycle makes the most of the temperature difference between surface and deepwater. Even though the OTEC concept is very old, it has not reached industrial maturity. The first formulation of the idea of such a plant to generate electricity from seawater thermal energy was made by J. D'Arsenoval in France in 1881 [8,9]. In 1930, his student G. Claude built a simple experimental plant of 22 kW in Cuba [10], and from that milestone several designs of small and medium scale were built and operated experimentally.

A 210 kW nominal plant on the island of Hawaii, producing 100 kW of net energy, successfully operated for six years in the nineties [11]. The National Institute of Ocean Technology (NIOT) of India, with the support of Saga University of Japan, built a floating pilot OTEC plant of 1 MW in 2001, shown in Fig. 1, that run in 2002 [8]. The success of this plant, known as Sagar Shakthi, drove many design and implementation projects around the world. Currently, there are about fifty countries, mostly in the Pacific Ocean, evaluating its implementation as an energy source and as a sustainable solution to water scarcity [12]. Lockheed Martin's Alternative Energy Development team is working on the final design of a 10 MW pilot plant for Hawaii which is expected to be built in 2013. The

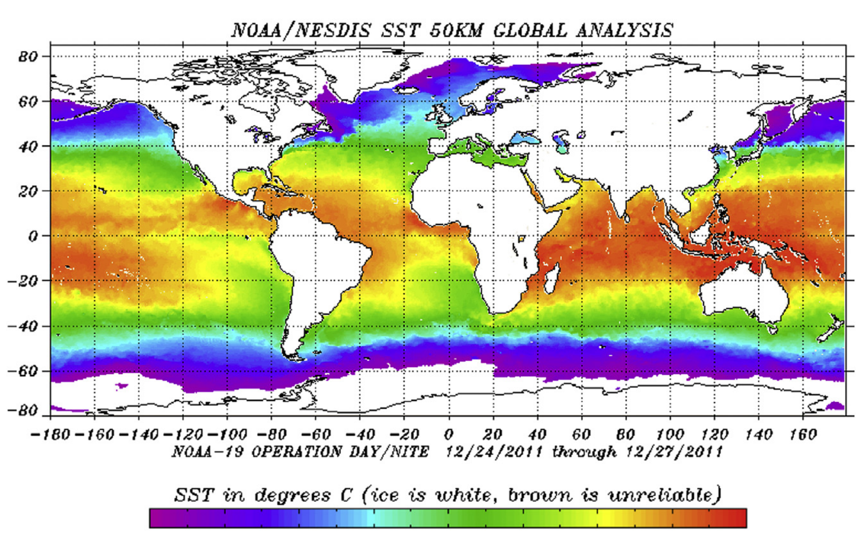

Fig. 2. Global sea surface temperature [15].