CHAPTER 72

STATUS OF U.S.A. OCEAN ENERGY RECOVERY ACTIVITIES

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Abstract

The state of the art of ocean energy recovery activity in the United States is described. The technologies discussed in the paper include extraction of wave, tidal, ocean thermal and ocean current energy. This status report is intended to provide a description of the various ocean energy technologies and an assessment of potential benefits that might be expected and potential problems that might be encountered.

Ocean Wave Energy Conversion

The present efforts in wave energy conversion in the United States are those at the Department of Energy (DOE), academic institutions and small specialized companies. Of the many types of wave energy extraction (McCormick, 1981), four are now under study and development in the U.S. These are the pneumatic wave energy converter, the contouring raft system, the tandem flap and two types of wave pump devices.

As illustrated in Figure 1, the pneumatic wave energy conversion system (PWECS) incorporates a wave-excited oscillating water column and a pneumatic turbine. The air above the water column is alternately compressed and expanded resulting in an alternating pressure difference across the turbine. A one-meter PWECS was tested in the second deployment of the KAIMEI in the Sea of Japan in 1985 (JAMSTEC, 1987). This effort was partially funded by DOE through the International Energy Agency. Improvements in capture chamber geometry and turbine performance are presently under study (McCormick, 1978; Richards and Weiskopf, 1987) at the U.S. Naval Academy. Efforts are also underway to improve the coupling of the counter-rotating rotors and incorporate a ring-generator into the design (Focas, 1981).

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Figure 1. Schematic of a U.S. Naval Academy Pneumatic Wave Energy Conversion System



Figure 2. Sketch of a Sea Energy Corporation Contouring Raft Wave Energy Converter

The contouring-raft system is under development by the Sea Energy Corp. (Hagerman, 1987). The configuration is similar to that in Figure 2. Sea Energy is planning a test of a prototype 500 kw "one-raft" system utilizing a yoke attached to a mooring point and working through a hydraulic power system. Model testing of a 1:25 scale system is being performed for regular and random waves.

The Q Corporation (Division of Van Dresser Corporation), with partial DOE support, has developed the tandem flap wave energy converter illustrated in Figure 3 (Scher, 1985). Because of its ability to capture both incident and a portion of the transmitted wave energy (due to reflection from the second flap), it is significantly more efficient than a single flap device. A 10 kw version of the tandem flap design was tested in Lake Michigan in 1987 with uncertain results due to power takeoff and other component failures. Q Corp. plans further system modifications and both tank and field tests in the future (Q Corporation, 1985; Wilke, 1985).

Two point-absorber systems for wave energy extraction have been developed in the United States. Figure 4 illustrates the principal components of the DELBUOY system developed by ISTI-Deleware Inc. (Hicks, 1988; Pless, 1982). The system comprises a light weight, shallow draft cylindrical buoy driving a submerged, single-acting positive displacement pump tethered to the seafloor. The motions of the buoy open the pump for the pressure stroke with energy stored in the natural rubber return springs used to refill the system. Clean seawater is drawn into the pump through prefilters to remove particulate matter. The flow of pressurized seawater from the pump is rectified using check valves with pressure surges damped by hydraulic accumulation. The pump output is then passed through the reverse osmosis filter with approximately 80% of the flow returning to the sea and 20% as freshwater pumped to the shore through low pressure plastic pipelines. Full scale system tests were performed at the University of Puerto Rico in 1980-1985 and to date eight full-scale prototype have been built and tested. Future designs are expected to produce up to 12,000 gallons per day of freshwater.

A second point-absorber system is the Wave Energy Module (WEM) illustrated in Figure 5 developed by U.S. Wave Energy, Inc. (Hopke, 1985). The WEM consists of two parallel discs connected with hydraulic piston pumps. One disc is buoyant and rides on the ocean surface while the other (reaction plate) is suspended at a depth where motion due to waves is small. Hydraulic fluid is transferred from the piston pumps to a high-pressure accumulator and is then fed to a hydraulic motor connected to a generator. A 1:40 scale model was tested at Worcester Polytechnic Institute and University of Massachusetts in the 1970s. In 1979 1:10 scale model tests were performed on Lake Champlain. Future plans include a full scale prototype test in the North Atlantic by the Newfoundland Oceans Research and Development Corporation.







Figure 4. Schematic Diagram of the DELBUOY System



Figure 5. Schematic Diagram of U.S. Wave Energy Inc. Wave Energy Module

Tidal Energy Conversion

Plans for a large scale electrical powerplant using the tides were proposed as early as 1919 for the Passamaquoddy Bay in Maine and the Cobscook basins of the Bay of Fundy. Tidal power studies for DOE (Wayne, 1977; Main, 1980) focused on the development of sites in Passamaquoddy Bay in Maine and Cook Inlet in Alaska. From a life-cycle cost point of view, the Passamaquoddy project is attractive. The Half Moon Cove tidal project site is illustrated in Figure 6. The design is for a single pool, single effect extraction cycle. The tidal basin is initially filled by opening gates during a flood tide. At high tide, the gates are closed and some three hours later generation of energy begins. The average output would be 10.6 MW for 5 1/2 hours. Application for a preliminary Federal Energy Regulatory Commission permit was filed in 1987 for this project.

Ocean Thermal Energy Conversion

The potential areas of OTEC deployment in the vicinity of the U.S. include: Hawaii, Gulf of Mexico, and territories and possessions in the Caribbean and Pacific. The magnitude of the OTEC resource in these areas has been estimated to be 10^5 MW. The most suitable sites for early OTEC landbased deployment are steep sloped islands where the cold deep water is found close to shore. A temperature difference of about 20°C can be exploited to run a heat engine that produces electrical power. One principle employed for OTEC is the Rankine closed cycle illustrated in Figure 7. A working fluid such as ammonia boils at tropical sea surface temperatures (i.e., 26°C) in an evaporator and this ammonia vapor in turn drives a gas turbine which runs a generator. The vapor is then condensed to a liquid by cold seawater (i.e., 6°C) pumped from 800-1000 m ocean depths, and the cycle is repeated. In 1979 a small, floating OTEC plant known as Mini-OTEC (Figure 8) was deployed off the Island of Hawaii by Lockheed in conjunction with the State of Hawaii and Dillingham Corporation. Mini-OTEC produced about 50 kw (gross). Sea Solar Power Corporation has developed a 100 MW floating plant closed cycle OTEC concept (Sea Solar Power, 1987) as illustrated in Figure 9. With a depth and length of 63 and 120 m respectively, the semi-submersible spar design would weigh about 25,000 metric tons and support a 1,200 m long 8.5 m diameter cold water pipe. It would use Freon-22 as a working fluid. The net-power output and auxiliary power requirements would be met by four 34 MW turbogenerator sets. In a cost-shared effort by Ocean Thermal Corporation, DOE and the State of Hawaii, a 40 MW pilot plant was designed in two phases. This plant is illustrated schematically in Figure 10 (OTC, 1984). The status of these projects is uncertain because of current low oil prices and the projected high initial capital cost for the OTEC plants.

Another OTEC power cycle currently under investigation by DOE is the open or Claude cycle as illustrated in Figure 11. In this concept, seawater itself can be considered the working fluid. After initial



Figure 6. Location Drawing of Half moon Cove Tidal Project



Figure 7. Schematic of a Closed-Cycle OTEC System



Figure 8. Mini-OTEC Producing Electricity off the Coast of Hawaii



Figure 9. Sea Solar Power Inc. OTEC Concept



Figure 10. Ocean Thermal Corporation 40 MW OTEC Power Plant at Kahe Point, Hawaii



Figure 11. Schematic of an Open-Cycle (Claude-Cycle) OTEC System

deaeration to extract noncondensible gases, warm seawater is flash evaporated in a vacuum chamber. Desalinated water vapor drives a steam turbine which in turn drives a generator. The water vapor is then either condensed in a direct contact condenser and discharged to the sea, or condensed with a surface condenser producing desalinated water as a byproduct. The latter feature is particularly attractive in arid tropical islands. A 165 kw open cycle OTEC experiment is planned to be conducted through a cost-shared project between DOE and the Pacific International Center for High Technology Research at the Natural Energy Laboratory of Hawaii, Kailua-Kona, Hawaii (Lewis, 1987). After a series of open cycle component evaluations (presently underway), an apparatus will be constructed and used to validate system performance predictions, identify technical issues and obtain data scalable to future commercial size plants. These experiments will be supported by an upgraded seawater supply system recently installed at the site (Lewis, 1988). This system included the installation of a 1.0 m diameter cold-water pipe capable of delivering 840 1/s (410 1/s to the OTEC facility, 430 1/s to State mariculture projects). The pipe represented the largest diameter, longest (2,060 m) pipe tranversing the steepest slopes ever spanned.

Ocean Current Energy Conversion

In waters adjacent to the United States, the significant ocean current resource is limited to the Florida Current and the Gulf Stream off the southeast coasts. Estimates of extractable energy from these sources vary from 10,000 to 25,000 MW. Two axial flow rotary current energy systems have been developed by U.S. companies. Aerovironment, Inc. with DOE support, developed a ducted hydraulic turbine called Coriolis for applications to the Florida Current (Figure 12). Rim suspended two stage counter rotating catenary rotors were designed to feed energy to rim-mounted generators. Completed research included hydraulic performance evaluation of the rotors, Analyses of anchoring and mooring configurations, and system economic studies (Lissaman, 1979).

A similar device was developed by the UEK Corporation and is illustrated in Figure 13 (Vauthier, 1984). Energy in a flowing stream is converted to mechanical energy by a two-stage turbine. A radial outflow stage is followed by an axial flow stage. The inlet flow is through a venturi-shaped 3.7 m diameter shroud which concentrates the flow energy. The entire mechanism is tethered by cables so as to be held in the current stream, or suspended below a support platform. The device has been tested in Chesapeake Bay by towing it behind a tugboat. The New York State Power Authority has purchased one unit for evaluation.



Figure 12. The Aerovironment, Inc. Coriolis Ocean Turbine



Figure 13. The UEK Corporation Underwater Kite

Conclusions

There is an abundant resource for ocean energy development in waters adjacent the United States and its territories. There is a high potential for extraction of energy in these waters from ocean waves, ocean thermal gradients, tides and ocean currents at selected sites. However, the existence of these resources does not imply immediately usable energy, since any device built to operate in these environments must be competitive with conventional land-based energy producing systems. Nevertheless, at some remote sites where conventional generation of power is relatively expensive, it is possible that an ocean energy source would provide economic power in the near future.

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