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An Overview of Marine Renewable Energy
해양 신재생에너지의 고찰

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Abstract : With the prospect of an increasing shortage of energy resources, there has been a growing interest in renewable alternative sources of energy. An increasing effort is being directed towards resolving the problems of extracting energy from the world's oceans, as they represent a vast potential source of renewable energy. This paper summarizes the extraction and conversion techniques of the ocean's energy resources, namely, energy derived from the ocean waves, tides, thermal gradients, and currents. For each energy extraction and conversion technique, case studies are discussed.

Keywords : ocean energy, renewable energy from the sea, waves, tides, ocean current, thermal gradient, Ocean Thermal Energy Conversion

요 지 : 에너지 자원의 부족이 점진적으로 증가할 것이라는 전망과 함께 재생가능한 대체 에너지에 대한 관심이 증가하고 있다. 잠재적인 재생가능에너지의 보고인 대양으로부터 에너지를 추출하는 방법을 고안하는 노력이 증가하고 있다. 본 논문은 해양 파랑, 조석, 온도차, 해류 등의 해양 신재생에너지 자원의 추출 및 변환의 연구동향을 요약 검토하였다. 각각의 에너지 추출과 변환 기술을 사례별로 논의하였다.

핵심용어 : 해양 에너지, 해양신재생에너지, 파랑, 조석, 해류, 온도경사, 해양온도차발전

1. Introduction

With the prospect of an increasing shortage of energy sources, there has been a growing interest in renewable alternate sources of energy. An increasing effort is being directed toward the problem of extracting energy from the world's oceans since the oceans represent vast potential resources of renewable energy (Carmichael and Feher, 1992; Krock, 1989; Mogridge, 1980).

This paper summarizes the extraction and conversion techniques of the ocean's energy resources, namely, energy derived from the ocean waves, tides, thermal gradients, and currents. For each energy extraction and conversion technique, case studies are discussed.

Before we consider the feasibility of extracting significant quantities of energy from ocean, it would be interesting to attempt to determine the magnitude of some of these natural processes. Isaacs (1973, 1976) and Seymour(1992) estimated the dissipation of solar power in the oceans. It indicates that thermal and salinity are far more than waves, tides, and currents in power dissipation rate in the oceans (Slotta et al., 1987).

2. Energy from Ocean Waves

There are more than a thousand different proposals for the utilization of wave energy in the patent literature (McCormick, 1976, 1981), and there are many ways to describe and classify them (Behrens and Champ, 1989; Budal and Falnes, 1975; Carmichael and Falnes, 1992; Hagerman, 1992; Hagerman and Heller, 1988; Kim, 1981, 1984; Kim and Magoon, 1983; McCormick et al., 1988; McCormick and Kim, 1987, 1997; Mei and Newman, 1979; Rogalski et al., 1979; Shaw, 1983). These devices can be classified into the following five categories:

1. Heaving
2. Heaving and Pitching
3. Pitching
4. Oscillating Water Column
5. Surging
6. Wave Focusing

For heaving float devices, the KN System by Danish Wave Power was conducted with 45 kW prototype in the North Sea. The Gotaverken's Hose Pump Wave Energy Conver-

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sion which has been conducted since 1980 is based on the "hose pump", a hose with helical pattern of steel wire reinforcement, which causes the hose to constrict when stretched. DELBUOY, two point absorber systems for wave energy extraction, has been developed by the International Science & Technology Institute, Inc. in the U.S. This 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. The water power desalination can be achieved by the reverse osmosis. Full scale system tests were performed at the University of Puerto Rico in 1980-85, and 350 gpd pilot commercial unit has been in operation at Coffin Island in Puerto Rico.

A Parallel Disk Wave Energy Module developed by the U.S. Wave Energy, Inc. combines the heaving and pitching motion. It consists of two parallel discs connected with hydraulic piston pumps. One disc is buoyant and rides on the ocean surface while the other 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. 1 kW, 1:10 scale model tests were performed on Lake Champlain, Vermont. The Contouring-Raft Wave Energy Conversion System by Sea Energy Corporation uses the heaving and pitching motion. Test of a prototype 500 kW "one-raft" system has been conducted for regular and random waves.

For pitching devices, Salter from the University of Edinburgh has developed a very efficient wave energy conversion device known as Salter Duck (Salter, 1974). The Duck is a cam shaped device that oscillates about a spine connecting many devices. The spine is long enough to span several waves and provides a steady frame of reference for power extraction. 1:10 scale model tests were performed at Loch Ness.

The Tandem Flap Wave Energy Converter by Q Corporation uses two flaps which are hinged at the bottom and allowed to move in the direction of wave. Because of its ability to capture both incident and a portion of the transmitted wave energy, it is significantly more efficient than a single flap device. A 10 kW Tandem Flap Wave Energy Converter system was tested in Lake Michigan in 1987.

A Pendulor system was developed by Professor H. Kondo at the Muroran Institute of Technology in Japan (Kondo, 1993). The pendulor is a pendulum gate which swings backwards and forwards in the opening at the front of a chamber facing the incident waves. The back of the chamber is a fixed wall, located a quarter wavelengths behind the axis of the pendulum pivot. A 5 kW system has been in operation in the bay of Uchiura near to Muroran in Hokkaido, Japan.

Oscillating Water Column 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 Pneumatic Wave Energy Conversion System was tested in the second deployment of the KAIMEI in the Sea of Japan in 1985 (JAMSTEC, 1987). A 500 kW prototype, Multi-resonant Oscillating Water Column by Kvaener, Norway, was constructed in 1980. In Japan, Shore-Fixed 40 kW Wave Power Plant was constructed on the shore of Sanze, East Sea. This plant consists of a caisson and air turbine generator, and Tandem Wells turbine was selected. The Wave Power Extracting Caisson Breakwaters developed by Y. Goda of Japan while he was with the Port and Harbor Research Institute has been built at Sakado, Japan. Caissons function as a breakwater and a wave power device at the same time. Another concept, Backward Bent Duct Buoy, developed by Ryokuseisha Corporation has an air chamber bent backward from the wave direction. Its originator, Y. Masuda, reported that this configuration of floating platform has a superior performance and that it has excellent conversion efficiency with low mooring force (Masuda, 1986). A 2.4 m scale model was tested at Yura in 1987 and at Mikawa Bay in 1988. Recently, Professor M. McCormick at Johns Hopkins University conducting tests for optimum design of the Backward Bent Duct Buoy system.

For surging device, Tapered Channel known as TAPCHAN has been in operation since 1986 at Toftestallen, Norway. This Norwegian device converts the wave energy into potential energy in a reservoir on the shore. Considerable effort has been expended on two wave focusing devices: Fresnel diffraction and refraction. The Norwegians have concentrated on Fresnel diffraction and have gone as far as to build a large wave tank to test their systems.

3. Energy from Ocean Tides

Tidal power is only worth harnessing in areas where a funnel-shaped bay or an estuary is of just the right shape for construction of the dam, and the tidal range has to average about 5 m to provide sufficient energy. (Department of Energy, 1989; Gray and Gashus, 1972; Lissaman et al., 1979; Song, 1987; Yum, 1983; Shaw, 1974; Warnock, 1987)

A. One-way, single-basin generation

This is the simplest form of tidal power utilization. Water is allowed to enter a bay through open sluices, which are then closed off at high tide. As the tide outside the basin recedes, the water is released through turbines, generating electricity. This scheme is characterized by about 5 hours of generation, followed by 6 to 7 hours of basin refilling.

B. Two-way, single-basin generation

This scheme permits power generation with water moving either from the basin to the sea or from the sea to the basin. More energy is generated by use of the two-way scheme than by a one-way scheme at the same location. However, the average available head is lower in a two-way method than in the one-way method. Thus, the turbines in a two-way scheme must be larger and are more expensive.

3.1 La Rance Tidal Power Plant, France

The La Rance tidal power station on the west coast of France, with an installed capacity of 240 MW, is the first tidal plant (Cotillon, 1974). The estuary of the Rance is located in one of the regions of world where the tidal amplitude is the greatest (13.50 m – 44') due to the obstacle presented by the Cotentin peninsula to the tide entering the English Channel from the Atlantic. The construction began in January 1961 and 24 units were placed into service in December 1967. The operational principle is the double-acting cycle which means that power may be produced during filling as well as during emptying of the basin. The structures associated this tidal power plants are:

- A lock permitting navigation between the basin and the sea
- The power plant with 24 bulb-type turbines
- Each turbine is rated at 10 MW
- A rock-fill dike (163 m – 535' long) closing off the rest of estuary
- The sluice gates, equipped with 6 gates, permit quick counterbalancing of water levels to fill or empty the basin

The power plant is equipped with 24 identical power generating units of 10 MW each. A horizontal 4-blade Kaplan turbine rotates at 93.75 RPM, and it handles a flow of 275 m^3/s.

The installed power is 240 MW, and the net annual productivity is 544 GWh.

3.2 Kislaya Guba, USSR

In 1968, the Soviet Union put into operation a 400 kW pilot plant in Kislaya Bay, called the Kisloqubskaya pilot plant. At the Kislaya Guba site, a sea cutoff of only 50 m length was sufficient to close in a tidal basin subject to a range of level variation of 1.3 m to 3.0 m. The tidal bulb turbine had a 3.3 m runner powering a 400 kW generator. It was to be the forerunner of a mode of construction which has been become universally accepted as the most cost effective techniques for tidal power barrage of the future (Bernstein, 1969; 1972).

3.3 Annapolis, Nova Scotia, Canada

The Canadian tidal power project is the 20 MW plant at Annapolis Royal, Nova Scotia. The powerhouse is located on Hog's Island in the lower reaches of the Annapolis River where an existing barrage protects the agricultural marsh lands from tidal flooding. Annapolis Royal is a single effect tidal power station designed to generate power during discharge from the reservoir into the sea. The plant contains a single "Straflo" turbine and has been operational since 1984 (Delory, 1986).

This project is considered a pilot project for the purpose of evaluating the operational characteristics of the large Straflo turbine and potential of such turbine for large scale tidal power developments in the Bay of Fundy (Shaw and Van Den, 1972).

3.4 Jiangxia Tidal Power Station, China

In China, tidal energy was built in 1959 with the installation of a 40 kW plant located in Shashan. A 165 kW tidal plant was later built in 1970 in the Shandong Province. Jiangxia tidal power station which is located on Zhejiang Province is one of China's key reservoir bi-directional tidal experiment power station. The total capacity is 3,200 kW.

3.5 Sihwa Tidal Power Plant, Korea

Sihwa tidal power plant is located on the Westside of South Korea, west of Seoul and south of Inchon. Single-effect flood generation type, with a capacity of 254 MW (25.4 MW per turbine, 10 units) has an annual generation of 552.7 GWh. It has 8 sluice gates, and the project was completed in 2011 with project cost of U.S. $355.1 million. (Kim, 2010)

4. Energy from Ocean Temperature Gradients

Ocean Thermal Energy Conversion (OTEC) technology is based on the principal that energy can be extracted from any two thermal energy reservoirs having different temperatures (Vadus and Giannotti, 1980; Vega, 1992). A temperature difference as low as 20°C can potentially be exploited to produce usable energy. Temperature differences of this magnitude prevail between ocean waters at the surface and a depth of 1000 m in many areas of the world.

In tropical areas, the surface layers of the sea are heated to around 25°C. But deep layers, from about 600 m, have a temperature of around 5°C. This temperature difference can be exploited on thermodynamic principles to run what is in effect a heat engine that produces electrical power. The principle used is called the Rankine closed cycles. Warm surface water is pumped through a heat exchanger (evaporator) where it gives up its heat to a working fluid, usually ammonia. The liquid vaporizes and expands to drive a generator. The vapor then flows through a second heat exchanger (condenser) and is liquidized, having given up its heat to cold water extracted from 600 to 900 m depths. The ammonia is then pumped back to the evaporator and the cycle is repeated.

Three basic OTEC designs have been pursued: closed cycle, open cycle, and hybrid cycle. In the closed-cycle system, a working fluid with a low boiling point (such as ammonia) is converted to vapor through heat exchanger, with warm seawater drawn from just below the ocean's surface. In the open-cycle system, warm seawater becomes the working fluid when it enters a vacuum chamber and boils rapidly. In both systems, the resulting vapor drives a turbine.

In 1979, a consortium of the State of Hawaii, Lockheed Missile and Space Corporation, and the Dillingham Corporation developed a 50 kW, closed cycle OTEC facility called Mini-OTEC off Keahole Point, Hawaii. It became the world's first successful closed-cycle OTEC plant to produce net energy at sea. In 1981, Global Marine and TRW deployed OTEC-1, a 1 MW closed-cycle floating OTEC facility, offshore of the big island of Hawaii. In 1984, a 40 MW land-based closed-cycle OTEC pilot plant was sited near Kahe Point, Oahu (Lewis et al., 1987; Lewis et al., 1988).

The only OTEC plant in the world is operated by the Pacific International Center for High Technology Research (PICHTR) on the Island of Hawaii. This 210 kW open-cycle experimental plant has been operational since 1993, and has produced the highest outputs of electricity and desalinated water ever achieved. The work has been sponsored by the U.S. Department of Energy (DOE) and the State of Hawaii.

5. Energy from Ocean Currents

There are three current energy extraction systems which are being considered. They are:

Axial Flow Converters
Radial Flow Converters
Linear Converters

Axial flow rotary current energy systems are analogous to a standard windmill where the axis of rotation is parallel to the working fluid flow. The Aerovironment version of the Mouton idea is called "Coriolis I." Peter Lissaman states that a multiple array of the turbines placed 30 km off the coast of Florida could supply 10,000 MW at a cost of 36 mils/kwh in 1977 dollars. This power would be sufficient for the daily needs of 10 million people.

Radial flow current extraction systems are characterized by having their axis of rotation perpendicular to the current velocity. Linear systems are not considered to show much promise as current energy systems because of their low efficiency, complexity, maintenance difficulties, and low survival probability.

Marine Current Turbines Ltd, based in Eversley, UK plan to install marine current turbines on steel monopoles. A typical 1 MW machine would have a pile diameter of 3 to 4 m at its base and a rotor diameter of 20 m. Marine Current Turbines plans to install a 300 kW, single-rotor test system near Lynmouth, UK, in mid-2002.

Hammerfest Strom as, a Norwegian company has installed a prototype "tide mill" on the seabed near the arctic tip of Norway that will use current motions to turn turbines blades and establish a generating capacity of 300 kW.

Korea had planned to be the first nation to trial commercial-sized power generation from ocean currents, with the first of its pilot turbines in place at Uldolmok, south-west of Korea. Researchers at the Korea Ocean Research and Development Institute (KORDI) chose the site because it has flows up to 12 knots. One MW pilot plant was installed with helical turbines. The experiment was intended to study the structural stability and efficiency of helical turbines, which adjust automatically to the changes in tidal flows.

6. Conclusions

1. There is an abundant resource for ocean energy development. There is a high potential for extraction of energy in these waters from ocean waves, tides, ocean thermal gradients, 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 system.

2. Since the original oil crises of 1973, many countries have launched programs to exploit the ocean energy options: waves, tides, ocean thermal gradients, currents, and biomass. In the latter part of the 1970s, many advances were made in the development of the various technologies required to convert these engines into more useful forms. Unfortunately, from the decade beginning in 1975, the United States changed from being a leading country in advancing ocean energy conversion to one of inactivity. A number of countries, recognizing both the necessity and marketing potential of wave energy conversion, expanded their programs. There seem to be a resurgence of interest in ocean energy worldwide in recent years.

3. The energy from the ocean is considered to be the cleanest energy. Although considerable technical advances have been made in extracting energy from ocean waves, tides, temperature gradient, current, and salinity gradient, there is reluctance in moving forward with projects by the international community. Perhaps, the reasons are that in each device, there are technical and environmental problems and the amount of energy produced in each category cannot address the entire nation's energy problem.

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