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Research and Analysis of Wave Energy Characteristic for Wave Generation System

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Abstract : Wave Energy is a derivative of the solar energy input to the earth, which is accumulated on open water surfaces by the action of the winds. Waves are disturbances in the water surface. This paper is interested primarily in progressive waves, which carry energy from one place to another. Waves are irregular in size and frequency. Moreover the surface of the sea is one of the most hostile environments for engineering structures and materials.

The idea of harnessing the tremendous power of the ocean's waves is not new. Hundreds of wave energy conversion techniques have been suggested over the last two centuries. Although many WECS (Wave Energy Conversion Systems) have been invented, only a few systems have been tested and evaluated.

This paper describes the characteristic of WES (Wave Energy System) in terms of, devices, resource and potential, etc,. Finally, this paper provides a summary of general and specific conclusions and recommendations concerning WECS potential in Korea.

Key words : Wave energy, Progressive wave, Oscillating Water Column, WECS(Wave Energy Converter Systems), WES(Wave Energy System)

1. Introduction

The constraints of WES have often slowed down wave energy development, but the advantages of wave energy are obvious, as it combines economic, environmental and social factors.

The power in a wave is proportional to the square of the amplitude and to the period of the motion. Therefore, long period (7-10 [s]), large amplitude (about 2 [m]) waves have energy fluxes commonly averaging between 40 and 70 [kW] per m width of oncoming wave. Nearer the coastline the average energy intensity of a wave decreases due to interaction with the seabed. Energy dissipation in near shore areas can be compensated for by natural phenomena such as refraction or reflection, leading to energy concentration. It is important to appreciate the difficulties facing wave power develop-

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ments, the most important of which are:

First, It is difficult to obtain maximum efficiency of a device over the entire range of excitation frequencies with the irregularity in wave amplitude.

Second, the structural loading in the event of extreme weather conditions, like typhoon, may be as high as 10 times the average loading[1].

It becomes apparent, that the design of a WEC (Wave Energy Converter) has to be highly sophisticated to be operationally efficient and reliable on the one hand, and economically feasible on the other. As with all renewable energy sources, the available resource and variability at the installation site have to be determined first. The power generation system in the sea has some problems such as construction cost and technology. The WES in shoreline is built into the shoreline and use the force of wave to push or rotate a mechanical coupling that in turn rotates a generator.

Finally, this paper presents the characteristic of WES, and the variety of potential WECS application in Korea.

2. Wave Energy

As with all renewable energy sources, the available resource and variability at the installation site has to be determined first. The limited experience with wave power schemes makes it possible to form only an incomplete picture of possible environmental effects caused by wave power system

Generally, the environmental impacts of wave energy conversion technologies are summarized in shoreline, nearshore and offshore. As stated previously, the peak-to-average load ratio in the sea is very high, and difficult to predict. The result is either underestimation or overestimation of the design loads for the wave generation system. In the first case, the total or partial destruction of the facilities is to be expected, with mathematical accuracy. In the latter case, the high construction costs induce high power generation costs, thus making the technology uncompetitive.

This paper describes the wave generation system in shoreline. This is fixed to the shoreline itself, which has the advantage of easier maintenance and installation. In addition this would not require deep-water moorings or long lengths of underwater electrical cable.

This paper presents the OWC (Oscillating Water Column) as the wave generation system in shoreline. OWCs use an enclosed structure that is partially submerged to harness the kinetic and potential energy encompassed in an ocean wave. A barrier wall is usually constructed on the ocean side of the construction area. The upper portion of the OWC structure is hollow with a port on the backside of the Wells turbine generator. The front wall of the enclosure extends into the water and needs to be fully submerged at all times. Due to this necessity the tidal fluctuations must be relatively small compared to the size of the structure[2].

Assume the dash linedrawn on Fig. 1 is the water level represented. If this were the case, when the incoming wave funnels into the structure, some of the airflow would escape opposite the wave direction because there would no seal forcing the air through the port on the back wall of the structure. The tidal fluctuations must not drop below that of the bottom edge of front wall in order to maintain operational parameters.

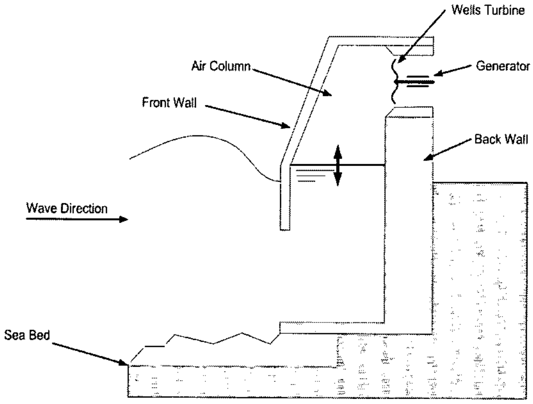

Fig. 1 OWC structure

In Fig. 1, when the wave approaches, it causes air to be forced into the air chamber and out of the port, near the back wall. When the wave retreats in the opposite direction, air is pulled from the port on the back wall through the turbine and out near the entrance of the front wall. OWC is included the Wells turbine. In essence the operating tolerances for wave conditions are very narrow. The turbine in itself was the major breakthrough in implementation of the OWC, utilizing two way unidirectional generator rotation. The use of a Wells turbine mechanical coupled with an induction generator are typical configuration of an OWC. The majority of wave generation systems, irrespective of location, utilize the movement of the waves to directly or indirectly drive OWC turbine.

2.1 Wave Energy Resource

The level of exploitable resource is among many factors, a determinate of geographical location and physical site (shoreline, nearshore or offshore). The relationship of the location of energy production to the end user is a key financial factor. The cost of transmission and connection can often outweigh the construction and equipment costs[3].

Wave power is at its strongest in open sea conditions where there is minimal dampening forces. As the waves move closer to land the power of a wave is reduced by the effect of dissipation against the rising seabed and a greater proliferation of contrary wind off the landmass. Upon hitting the shore it is estimated that on average only a tenth of the wave's power remains. The resource potential by wave height and average time is illustrated in table 1.

Table 1 Resource potential by wave height and avg time

Time	H_s	T_z	P(kW/m)
Jul-93	0.93	5.53	2.39
Aug-93	0.74	5.77	1.58
Sep-93	0.7	5.72	1.40
Oct-93	0.77	5.75	1.70
Nov-93	0.74	5.99	1.64
Dec-93	0.59	5.45	0.95

where, H_s is a significant wave height, T_z is average time between upward movements across mean. P is given as follow:

$$P=\frac{H_s^2T_z}{2} \tag{1}$$

2.2 Wave Energy Economics

There is still no overall consensus no design or location that allows for a long-term definitive financial model based on standardized equipment. There remains considerable scope for dramatic cost reductions offered by large-scale manufacturing and longer-term reliability. The last decade has witnessed a 50% reduction in production and operating costs. It does not yet compete with fossil fuel generation but it is already competitive with other renewable. It is also competitive for niche markets such as remote islands, competing against conventional diesel generated electricity supply.

The three different locations for wave generation systems have differing economics with variations in installation, maintenance and operational costs. Table 2 presents the location characteristic.

Table 2 Location characteristic for WGS

Items	Shoreline	Nearshore	Offshore	Note
Power potential	Low	Medium	High	
Connection	Simple	Difficult	Difficult & expensive	
Servicing	Low	High	Very high	
Maintenance	Low	High	Very High	
Conversion method	Turbine/ generator	Turbine/ generator	Turbine/ generator Or direct drive	OG

The production price of wave energy should enable the commercial application of many devices well before 2010. The evidence data is aggregated from IEA and DWA, and the trend of production cost is shown in Fig. 2.

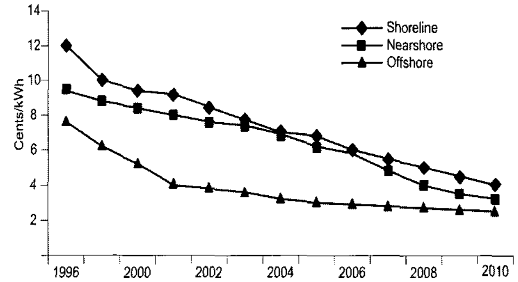

Fig. 2 Trend of production cost

2.3 Wave Energy Characteristics in Korea

The several primary sources of wave energy in Korea are built up by local trade winds, swell, and swell from similar storms. High waves are also generated by typhoon, but this is relatively rare wave events, occurring no more than a few times a year. Such waves represent a significant hazard that must be considered in the design of a wave power plant.

In Busan, wave power is estimated by the significant height(H_S) and the average time between upward movements across mean(T_Z).

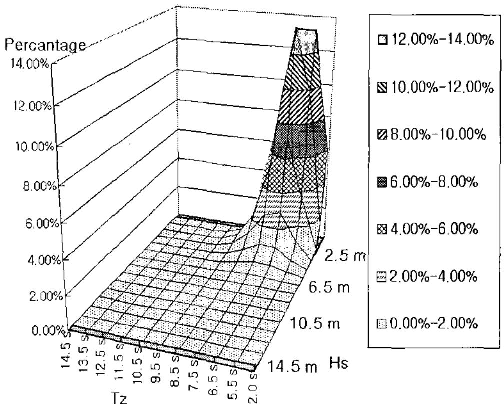

Fig. 3 Annual wave energy resource

Generally, refraction and shoaling significantly reduce wave power densities in shallow water, along the 5m depth contour, they are roughly 20[%] lower than along the 80[m] contour. Multiplying the average wave power along a given depth contour by the length of each costal segment and by the number of hours in a year, and summing the results for all segments, gives the annual wave energy resource for Busan. This result is plotted in Fig. 3.

3. Wave Energy Conversion System

Although many WECS(Wave Energy Conversion Systems) have been invented, only a small proportion has been tested and evaluated. A WECS may be placed in various possible situations and locations on the ocean. The main type of shoreline device is the OWC, which are the land-based systems. WECS can be categorized as OWC, WS(Wave Surge) and PD(Pitching Device). OWC generates electricity from the wave-driven rise and fall of water in a cylindrical shaft. The rising and falling water column drives air into and out of the top of the shaft, powering an air-driven turbine.

OWC consists of a partially submerged, hollow structure that is open to the sea below the water line. This encloses a column of air on top of a column of water. Waves cause the water column to rise and fall, which alternately compresses and decompresses the air column. This trapped air is allowed to flow to and from the atmosphere via a Wells turbine, which has the ability to rotate in the same direction regardless of the direction of the airflow. In the wave energy system, one of the major problems with shoreline-based OWCS is their construction. This problem can be solved a new OWC such as the EOWC (Energetech OWC). Energetech in Australia developed the EOWC, which represents the next stage in development of the OWC. It uses a novel, variable pitch turbine instead of the Wells to increase the systems efficiency[4].

Now, WECS economics have improved quite a bit over the last 10 years. Fig. 4 shows projected cost development over time. WECS' costs appear to be following a trend similar to other renewable technologies i.e., significant cost decreases over time.

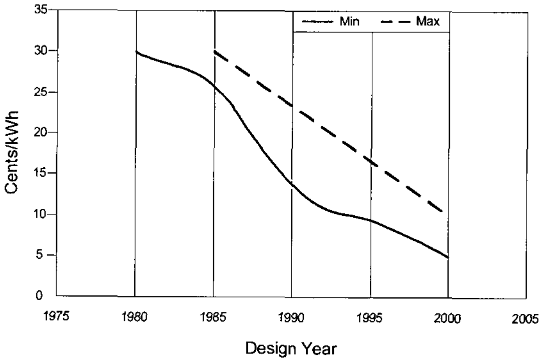

Fig. 4 Trend of WECS cost

Wave energy systems generally have greater capacity factors than wind or solar systems. A wind energy conversion system is compared to a wave energy system. Both systems are rated at 50 [MW] and are sited in the Busan. Costs have been estimated from this 1995 study using a construction cost index. Using index, construction costs have increased 13.7[%] over the period from 1995~2000.

This comparison is illustrated in Table 3 using an example for Busan utilizing data obtained from the Development Report[5].

Table 3 Comparison of wind energy and WECS in Busan

Parameter	Unit	System Type		Wave/Wind Ratio
		Wave	Wind	
Rated Output	MW	50	50	1:1
Capacity Factor(Delivered Electricity)	-	0.402	0.173	2.32:1
Annual Output	MWh/yr	175,998	75,918	2.32:1
Capital Cost	$/kw	2,716	1,306	2.07:1
Total Electricity Cost(O&M cost + Capital Recovery cost)	cents/kWh	10.62	8.00	1.33:1

In wave energy system, costs are still too high, and the technology remains uncertain. In order to this part to be successful, there is a need for standardization of subsystems and components, which will allow for modularization and ultimately make this part competitive to other forms of renewable power generation.

4. WEC Technology and Simulation

The main type of shoreline device is the OWC, which is shown schematically in Fig. 1. It consists of a partially submerged, hollow structure, which is open to the sea below the water line thereby enclosing a column of air on top of a column of water.

In this paper, the 0.2[kW] simulation plant was designed as a testing facility, which is shown in Fig. 5.

The testing facility is simulated with wave frequency and wave height. The following simulation results were used to evaluate the WECS. Theoretical models in the time domain and a frequency domain have been created and the available data have to carry out to calibrate with water tank tests or sea tests. The simulation results are shown in Fig. 6.

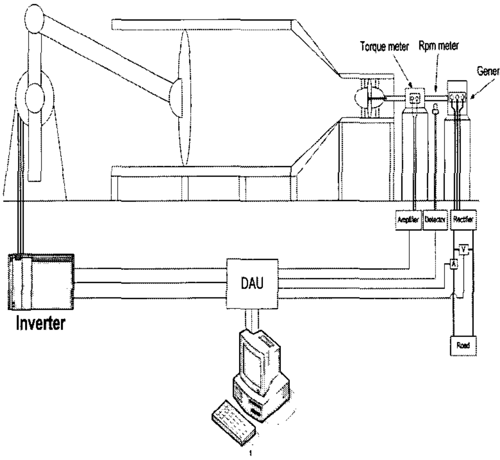

Fig. 5 Schematic diagram of testing facility

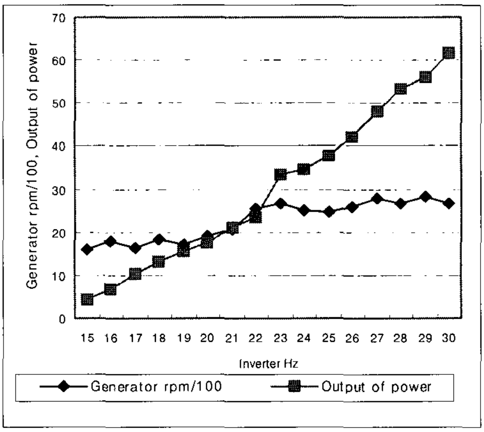

Fig. 6 Simulation results

5. Conclusion

This paper has summarized some of the key commercial and technology drivers generic to the emerging wave energy sector. There is a wide variety of convertsion schemes. Although many wave energy systems have been invented, only a small proportion has been tested and evaluated. In Korea, wave energy conversion systems are in an early stage of development and are not yet commercially viable. WECS is not expected to be available on a large scale within the near future due to limited research and lack of funding. So, many research and development goals remain to be accomplished.

This paper recommends that researchers carry out further wave tank tests and improve their theoretical simulations in order to address these performance issues.

The successful further development of this technology requires committed and consistent government support. Finally, Korea government needs to evaluate the relative costs, status of development, and potential applications for each of its many indigenous renewable energy resources.

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Author Profile

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He was born in Kyung-Nam, Korea. He received the B. E. degree in Marine Engineering from korea Maritime Univer- sity in 1983. Since 1983, He has been with the Zodiac(England Company) including early 4 years of System Engineer. He received the M.E and Ph. D. degrees from Korea Maritime university, Korea, in 1989 and 1996, respectively. He had been with the Agency for Defense Development (ADD) as a researcher from 1989 to 1992. From 1992 to 1996, he was an Assistant Professor in the Department of Industrial Safety Engineering at Yangsan Junior College. In 1996, he joined the Division of Mechatronics Engineering at Korea Mari- time University. During 2001-2002 he had been in visiting professor, Department of system engineering, university of Wales in U.K. From 2001, he is a Korea R&D center manager of K. O. Tech.(U.K. company). His research interests include electrical drive systems, PC-based control applications, energy generation system and ship automation system.