Status for Development of the Open Sea Test Site for Wave Energy Converters in Korea

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***Abstract*— The status of development of the open sea test site for wave energy converters in Korea was described in this paper. In order to promote the dissemination of wave energy and to accelerate the technology development of wave energy converters (WECs), Ministry of Oceans and Fisheries in Korea is supporting the project for the development of the open sea test site from 2016. Site selection, design and consent for test site have been completed by the mid of 2018. Constructions of submarine cable & connectors, substations, SCADA system, onshore buildings, performance assessment system, and test site operation system are being under development. They will be finished by the next year (2019). In this paper, the backgrounds, the achievements, and ongoing process for development of the open sea test site for WECs in Korea were reported.**

***Keywords*— Wave energy converters, open sea test site, grid connection, infrastructure, performance assessment, test site operation**

I. Introduction

Ministry of Oceans and Fisheries in Korea has been driving the project, 'Development of open sea test site for wave energy converters' in order to accelerate the commercialization of the wave energy converters. Korea Research Institute of Ships and Ocean Engineering (KRISO) as main contractor started the project at May 2016 with Jeju University and will complete the project at the end of 2019. In the test site, the performance assessment, demonstration of installation and dismantlement, and optimization of the operational technology for wave energy convertors (WECs) will be carried out. We call the test site K-WETEC (Korea Wave Energy Test and Evaluation Center) tentatively. KRISO contracted with European Marine Energy Centre (EMEC) [1] about supporting the development of K-WETEC. EMEC consults and comments the design, construction, and operation of wave test site.

An open sea test is an essential process for commercialization of WECs. Technical readiness levels (TRLs) for WECs were introduced by many organizations, for example IEA OES [2]. For all kinds of TRLs, commonly the performance of WECs should be verified as scale model or full scale prototype and single device or multi- or arrayed devices in the open sea, before starting commercial sale business for electrical energy generated from WECs.

An infrastructure for testing WECs in open sea will help to accelerate the commercialization of WECs. The infrastructure, i.e. test site, will reduce the time, cost, and uncertainty in order to test the developer's WECs in open sea. The test site will supply the survey data, prepare a marine space occupation & utilization consenting and an electrical grid connection allowance, and lend the submarine cables & substation. The test site will get several kinds of approvals in consent processes of WEC performance test together with developers.

Many open sea test sites for WECs, e.g. EMEC, Wave Hub [3], BIMEP [4], SEM-REV [5], WETS [6], and so on, have been developed. No. of berths, water depth, and electrical capacity have been investigated as 4 ~ 6, 20 ~ 100 m, and 5 ~ 20 MW, respectively.

Design rated powers per unit module of the commercial WECs, such as 1 MW for Penguin [7], 1 ~ 1.5 MW for CETO 6 [8], 1 MW for WaveRoller [9], have been investigated, and it was found that the power capacities of the WECs are less than or equal to 1.5 MW.

Development process of the 5 MW grid connected open sea test site of 5 berths are composed of as follows;

- Selection and design for test site and facilities
- Consent for ocean space occupation & grid connection
- Construction of power transfer system in offshore and on shore
- Establishment of Supervisory Control and Data Acquisition(SCADA) and control center
- Development of performance assessment system
- Development of test site operation system

In 1st year (2016), the western area of Jeju island was chosen as the test site because of abundant wave energy, low marine traffic, enough electrical capacity transmitted to national grid, good accessibility of an harbor, and availability of submarine cable and substation. The position of each berth within the test site was also determined. The submarine cable routes and protection methods were decided, and the offshore substation were designed as shown in Fig 1. By the mid of 3rd year (2018), the consenting processes for public ocean space occupation and electrical connection to grid have been completed.

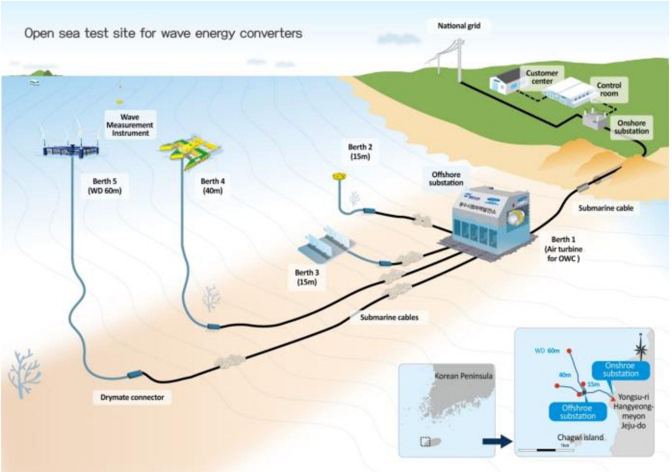

Fig. 1 Concept design for open sea test site for wave energy converters in Korea, K-WETEC

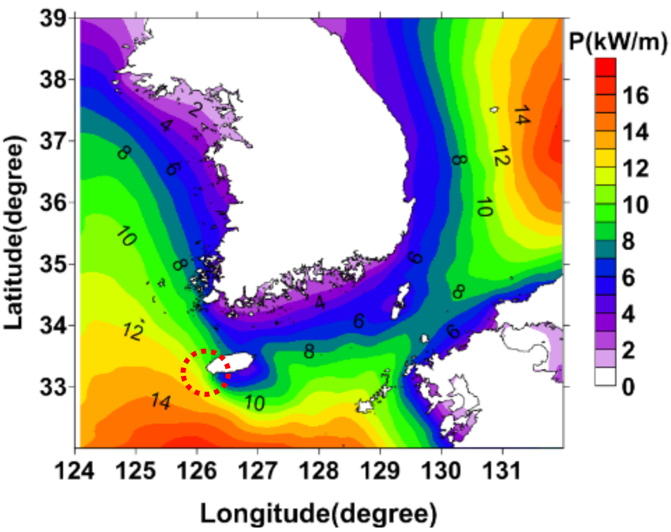

Fig. 2 Average wave energy density of Korea during 1979~2003 [10] and the position of test site at the center of the dotted red circle

In 3rd year (2018), the submarine cable offshore substation and electrical grid connection will be constructed. In 4th year (2019), the supervisory control and data acquisition (SCADA) system and control facilities including building will be constructed. The practical guideline for performance assessment corresponded to the international standard, such as IEC 62600 documents, will be drawn up, and measurement & analysis system for both input of wave energy and output of electric power will be constructed. The operation and maintenance manual of the test site will be written. A long-term road map for operation including a self-support method will be established.

The open sea test site will be facilitated to evaluate the performance of the WECs developed for adopting at Korea and east Asia, and to perform the type testing of certification system for WECs. Floating offshore wind turbines can be tested and the performance will be evaluated in the open sea test site.

II. Site Selection

Consideration points for selecting open sea test site for WECs were chosen as wave energy density, port and harbor facilities, marine traffic, electrical grid connectivity, social acceptability, construction cost, and government support endeavor.

Offshore area near Yongsoo-Li of Jeju island, in which Yongsoo 500kW oscillation water column (OWC) pilot plant has been constructed, was chosen as the open sea test site for WECs. The area has been known as the one of the highest wave energy area in the shore of Korean peninsula as shown in Fig. 2. Four harbors of various size are located within 15km. The marine vessel traffic in the region was relatively low. Good relationship with fishermen and residents has been kept since the previous Yongsoo 500kW oscillation water column pilot plant. The caisson structures, submarine cable, and onshore substation of the pilot plant in Fig. 3 will be converted as the facilities of test site. Thus, the construction cost could be minimized. Since the Jeju local government has a motto, ‘carbon free island’, the local government support the development of the wave energy.

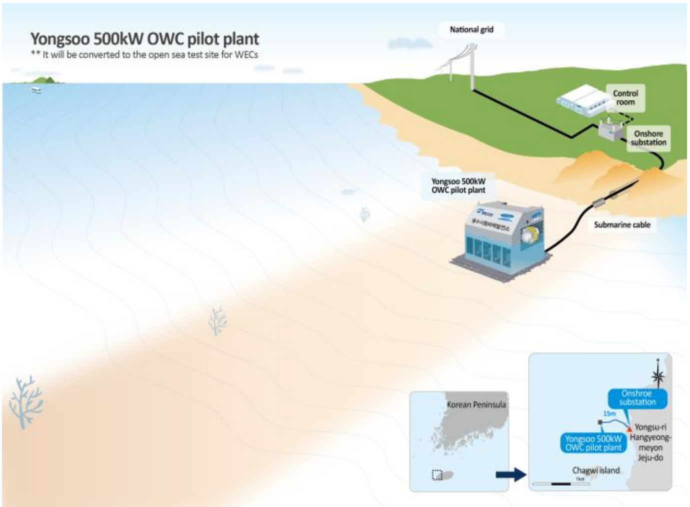

Fig. 3 The offshore substation, or former Yongsoo 500kW OWC pilot plant, and submarine cable from the substation to shore at beginning of developing the K-WETEC

III. Completion: Design and Consenting

A. Top design requirements and specifications

Functional requirements at top level for the open sea test site for WEC are given as follows:

1) Evaluate the performance of WECs
2) Demonstrate the installation and dismantlement
3) Optimize the operational technology
4) Verify the grid connectivity

Specifications of the test site are determined by surveying the required capacities of WECs and specifications of known open sea test sites, and from the comments of potential customers of K-WETEC in Korea as follows:

1) WECs working at various water depths of 15m, 40m, and 60m can be tested
2) All of electricity generated from WECs can be transmitted to the electrical grid within 5 MW.
3) Five WECs can be tested simultaneously.
4) Performance assessment system under IEC/TS 62600-100 document should be adopted.

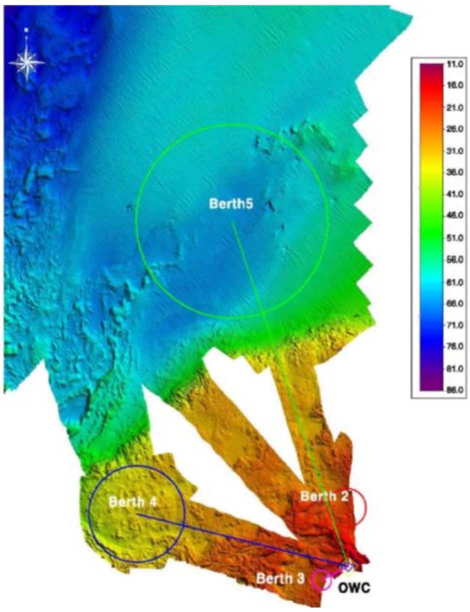

Fig. 4 The position of each berth on bathymetry map of K-WETEC

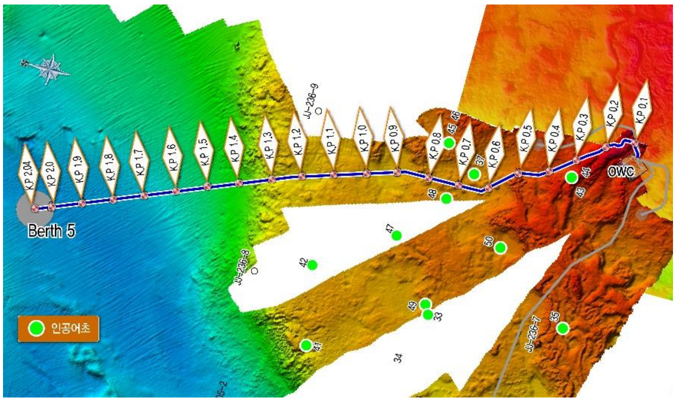

Fig.5 Cable routes for berth 5 on bathymetry map of K-WETEC

B. *Birth selection*

The position and area of each birth were determined in order to satisfy the specifications and top requirements. All berths on the bathymetry map are marked as circles like shown in Fig. 4. Target WECs to be tested are described as follows:

1) *Berth 1*: Air turbines for oscillating water column WEC can be tested. It is located within the offshore substation, which was Yongsoo OWC pilot plant. After finishing the performance assessment of current two OWC turbines and ducts, they are altered to OWC air turbine test berth. In the one duct, namely test duct, the test air turbine will be installed, and in the other duct, namely flow control duct, flow control valve will be assembled. With the test air turbine, the generator, PCS, and controller can be installed. The flow control valve adjusts the ratio of air flow rate between test duct and flow control duct, and it will simulate the air chamber size required for the test air turbine. Details are presented in AWTEC2018 by Kim et. al.[11]

2) Berth 2 or berth 3: Oscillating wave surge converters or any scale down model of WECs can be tested. Berth 2 and berth 3 are located in the 15 m water depth near offshore substation. We have selected the minimum wave distortion area from wave reflection and diffraction due to offshore substation. The occupied area for berth 2 and berth 3 are 100 m diameter and 200 m diameter, respectively.

3) Berth 4: Pilot or real scale of floating or submerged WECs can be tested. This birth has flat area of 500 m diameter with 40 m water depth considering normal diving depth limit know. Floating wind turbine also can be tested in this berth.

4) Berth 5: Pilot or real scale of floating or submerged WECs can be tested at deeper water depth than berth 4. This birth has flat area of 1000 m diameter with 60 m water depth. For the larger size WEC, 60 m water depth is determined in order to get the safety of mooring of floating system. Floating wind turbine also could be tested in this berth.

C. *Cable route and substation design*

Cable routes for berth 2, 3, 4 and 5 are determined on satisfying minimum length subjected to avoid maximum bending radius as shown. Fig. 5 shows an example of cable routes of berth 5.

Submarine cables from offshore substation to berth 2, 3, 4, and 5 are laid on with double protections. Firstly, the cast iron pipe protects the cables. Secondly, the stone bag protects the first protected cables. For the end linked with WEC, the cable are protected by UP-pipe and FCM instead of cat iron pipe and stone bag, respectively, in order to facilitate connection of submarine cable to dynamic cable, repeatedly.

Submarine cable is chosen as 22.9kV/180A, 3 core, and double armored cable with 24-line single mode fiber optic cable and 3 core low voltage cable. Since it should endure the fatigue loads from frequent installation and dismantlement, the dynamic cable concept: double wire for armoring and metallic screen for shielding was adopted to submarine cable.

Single wire for armoring and zinc metal block is generally used for general static cable.

D. *Consenting*

The consenting process for K-WETEC for 5MW open sea test site is summarized as shown in Fig. 6. We have gotten many kinds of approval document from various governmental institutions.

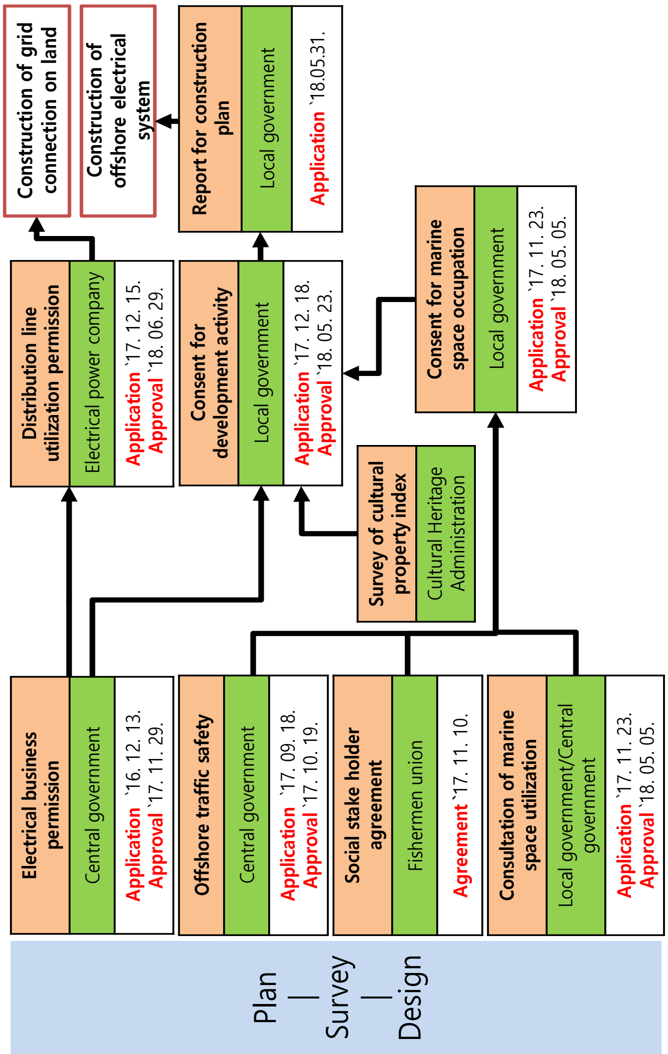

Fig.6 Consenting process of K-WETEC

IV. Ongoing : Construction, Onshore Building & SCADA, Performance Assessment System, and Operation System

A. *Construction*

In this year (2018), all of cables will be installed along with the designated routes with protections. The onshore and offshore substations will be constructed. The contraction with cable installation company has been made. The additional survey and adaptation of installation ship have been made. From the August of 2018, the cable installation will be started.

B. *Onshore buildings*

Customer center, control center, and equipment storehouse will be remodeled or newly constructed near onshore substation in next year (2019).

C. *SCADA(Supervisory Control and Data Acquisition)*

SCADA are composed of marine surveillance system, facility monitoring system, and environmental monitoring. In marine surveillance system, the ships navigations are monitored by the AIS, V-pass, and X-band radar. For most of ships they installed AISs on their ships and the control manager in control center recognize their identity. For small fishermen boats, the control manager also aware their identity by V-pass which is mandatory system for rapid response in the event of a marine accident. X-band radar will let the manager know trace of the unidentified ships or small floating one.

Facility monitoring system covers the status monitoring for electrical and mechanical devices of offshore substation and onshore substation. The CCTV can help the manager to see the real situation inside and around the building in remote. Many CCTVs and voice broadcasting system will be installed in the offshore substation and onshore substation.

Environmental monitoring system includes meteorology and oceanography data, from wave rider, ADCP current profiler, CTD, and public data from Gosan meteorological center which is 4 km apart from offshore substation. Collected meteorology data includes wind speed, wind direction, air temperature, humidity, etc. Oceanography data includes wave, current, water temperature, salinity etc. The data are collected and stored in server equipment as online or offline.

D. *PERFORMANCE ASSESSMENT SYSTEM*

Some of authors are participating and referring the technology standard activity about performance assessment in IEC TC114[12], IEA OES[13], and ITTC SCHMMRED[14] in order to carry out the performance assessment of WECs by international standard methods.

Authors want to have a role of a type testing lab with the open sea test site for WECs. We will develop also internationally accredited the performance assessment system. Authors predict that certification system will be established domestically and internationally. Under the certification system, WEC accreditation labs would accomplish several WEC type tests: power performance, mechanical loads, acoustic sound, and power qualities. In our test site, we are firstly preparing power performance assessment by IEC/TS 62600-100. Since the other type testing items are being developed and not completed yet, we are referring and will participate the activity of developing the other documents of IEC 62600.

The fixed oscillating water column type WEC, which is 500kW OWC pilot plant, and floating pendulum type WEC would be tested in berth 1 and berth 4 by next year (2019). Wave energy input and electrical powers are measured simultaneously, and the power matrix will be calculated in compliance with the IEC/TS 62600-100.

We are also referring the activity of IECRE[15], i.e. certification system of IEC for renewable energy applications including marine energy, IEC TC88[16], i.e. technical committee for standardization in the field of wind energy generation systems, and domestic test sites for wind turbines in order to get reference information for developing the performance assessment system of WECs.

E. TEST SITE OPERTAION SYSTEM

We are developing the operation system based on organization of K-WETEC which is classified into 4 teams: customer response team, consent team, facilities management & safety team, performance assessment team on the assumption of operation as the subsidiary of KRISO.

The customer response team should have role on contraction, marketing, and international/domestic cooperation. The customer response team should define and discuss the work scope with developers. The consent team should get a consenting or approval about marine occupation and electrical power generation. The facilities management and safety team should manage the submarine connectors & cables including cable protections, offshore substation, onshore substation, control center, and equipment storehouse. The team should has a responsible for safety of all facilities and persons within test site. Performance assessment team start their works by requesting from any developers who use berth in our test site or other test sites. Performance assessment for WECs can be accomplished regardless of the place of test site.

Role of each team should be defined, and the working manual and standard document forms for each team will be completed.

In addition to the operation system, we are preparing the self-operation. Thus, we should predict and promote the test demands by meeting with developers, investigating the state-of-the-art reports, and participating in conferences. We are estimating the income from demands and outcomes for expense, we are trying to minimize the expenses and maximize the test demands.

V. SUMMARY

A project for the development of the open sea test site for wave energy converters in Korea was started from June 2016. Site selection, design and consent for test site has been completed by the mid of 2018. Constructions of submarine cable & connectors, substations, SCADA system, onshore facilities, performance assessment system, and test site operation system are being under development. They will be finished by the next year (2019).

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