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A Combined Multi-Site and Multi-Device Decision Support System for Tidal In-Stream Energy

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Abstract

This paper combines site and device suitability approaches into one framework to assist stakeholders in identifying locations fit for Tidal In-Stream Energy (TISE) extraction as well as nominating devices that are matched to the conditions of those locations. A Matlab-based decision support system is developed using the framework. Site-Device matching is performed considering resource data, device power generation, energy production, and cost. A case study, involving four sites in the Philippines, is presented. Hydrodynamic simulations using DELFT3D are done. The suitability of modeled TISE conversion devices is investigated over several locations in the case study. Device nominations are made for respective locations using highest energy production as dominating criterion.

Keywords: Tidal Energy;Site and Device Matching;Decision Support System; Hydrodynamic Simulation

1. Introduction

The Ocean renewable energy industry has grown quite considerably these past 5 years. Quite a number of energy extraction systems are already in the water [1]. Due to their similarity to wind energy conversion devices, machines that extract power from tidal currents, which are more predictable than wind resource, are recently gaining project contracts around the world [2].

A few groups have worked on site suitability and an interesting decision support system is discussed extensively by [3] with details on assessment criteria that can be adapted by groups who plan to develop tidal current power plants. Research has also been published in studying the performance of various devices for specific sites as in [4], [5], and [6]. Even with the existing site suitability methodologies available and the work done for site-specific device performance studies [7][8], there is a need to develop

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a combined site and device framework by which suitable locations are further matched with suitable devices. This paper focuses on a systematic method of matching tidal in-stream energy conversion (TISEC) devices to locations in suitable sites.

Nomenclature	
P	electrical power
v	depth-averaged velocity
ρ	density of sea water
η	water-to-wire efficiency
A	capture area of energy conversion device

2. Methodology

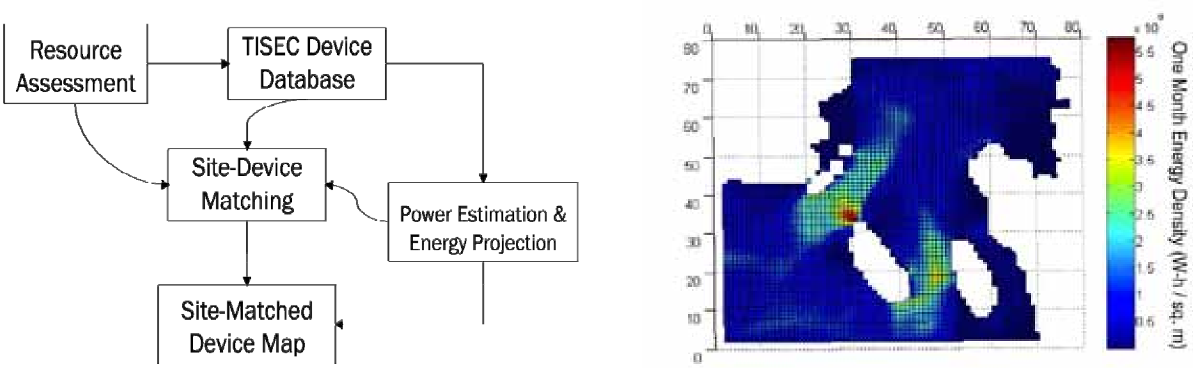

Fig. 1. (a) Site-Device matching framework; (b) Energy density map for Matnog, Sorsogon, Philippines

Figure 1-a shows the general site-device matching framework that this work uses to develop a decision support system to assist stakeholders in choosing which devices to place in which locations.

Resource assessment was done using a DELFT3D-based hydrodynamic simulation similar to that used in [9]. The depth-averaged velocity data were then transformed into power data using equation (1) and energy density maps were generated in Matlab^{TM} such as that shown in Figure 1-b.

$$P = 0.5\, \rho\, \eta\, A\, v^3 \text{ (Watts)} \tag{1}$$

A database for TISEC devices with their corresponding device characteristics is found in Table 1. Using eq. (1), the power output of a device subjected to the resource at hand is calculated for different regions of operation (before cut-in speed, between cut-in and rated speed, between rated and cut-out speed, and at cut-out speed and beyond) as discussed in [2] and [9].

Table 1 Summary of TISEC Device Properties / Characteristics

TISEC Devices	Cut-in Speed (m/s)	Rated Speed (m/s)	Cut-out Speed (m/s)	Capture Area (sq. m)	Rated Power (kilo-Watts)	Water-to-Wire Efficiency
EnCurrent (x200 units)	1.5	3	4	1.16 x 200	5 kW x 200	0.31
ERI@N (x133 units)	1	3	4	1.50 x 133	7.5 kW x 133	0.36
HS1000	1.1	2.7	4	346.00	1000 kW	0.29
Open-Centre	0.7	2.5	4	78.00	200 kW	0.32
Gen5 (x6 units)	1	2.5	4	60.00	168 kW x 6	0.35

2.1. Site Suitability

The four sites chosen in the case study presented in this work were pre-selected based on the following criteria:

- Straits or channels with reportedly high current velocities
- Not in navigation lanes
- Not in marine protected areas
- Depth is >10m but <100m
- Accessibility is < 5km from a support terminal

2.2. Device Suitability

For each of the candidate sites found suitable, device suitability scores for entries in the TISEC device database are calculated based on their annual energy output, relative levelized cost of energy, and availability.

Annual energy output is just the summation of hourly power outputs for the location with the corresponding device simulated as installed. Hourly depth-averaged velocities from the DELFT3D simulation for 720 hours or 1 month is used as an input series to calculate the power generated using eqn. (1). The monthly energy output, or the summation of hourly power outputs for the month, is simply multiplied by 12 months to come up with the annual energy output.

The relative levelized cost of energy, in $ / MWh, is defined to be the total project (installed device/array) cost divided by the total energy output of the simulated power plant for a lifetime of 20 years. The qualifier, “relative”, is used to signify that only the project cost is used and that other costs (e.g. maintenance, operation, etc..) are assumed to be the same for all tidal current power plant setups.

Availability is defined as the ratio of the number of hours that the device is in operation (producing power) to the total number of hours in the month.

The power plants that are assessed in this study are sized up to be rated at 1 MW power, hence, the devices that have lower rated power are assigned to have a multiple-unit / array configuration.

3. Results and Discussion

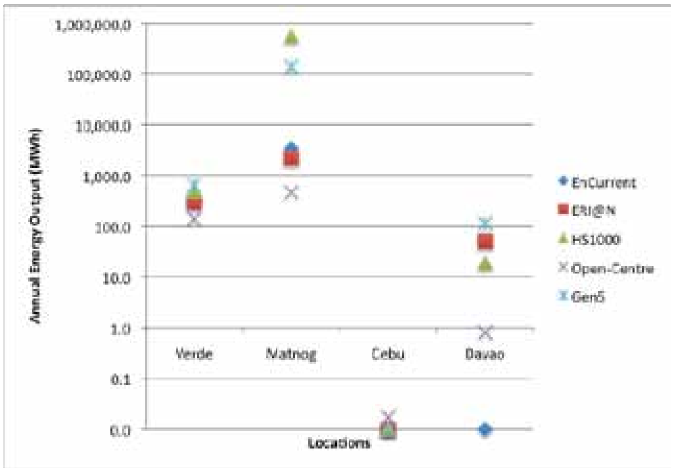

Fig. 2. (a) Device Annual Energy Projection for Various Sites; (b) Locations of Philippine Study Sites

The annual energy output of the power plants using different TISEC devices / device arrays in the four study sites are shown in Figure 2-a. The locations of the sites are found in Figure 2-b. Note that the Cebu site does not have a substantial energy yield compared to the other locations. It is also observed that the device that has the highest energy yield varies across locations.

Table 2 Relative Levelized Cost of Energy for different devices in various locations

	Relative Levelized Cost of Energy ($/MWh)			
TISEC Devices	Verde	Matnog	Cebu	Davao
EnCurrent (x200 units)	$165.85	$17.44	-	-
ERI@N (x133 units)	$207.68	$27.66	-	$1,197.66
HS1000	$103.28	$0.09	-	$2,644.36
Open-Centre	$366.82	$109.81	$2,975,614.50	$64,384.98
Gen5 (x6 units)	$79.23	$0.37	-	$456.92

Table 2 helps stakeholders decide which sites have feasible power plant development possibilities. For instance, we see that it is impractical to develop a tidal current power plant in Cebu because of the resulting high cost of electricity. The Matnog site seems to be the most viable options while Verde remains attractive and with Davao just barely making the cut.

The score radars for suitability of devices in the different sites are shown in Figure 3. Note that the higher the value on each score axis, the more positive the contribution is to the suitability of that device for the corresponding site. By calculating the area of the triangle formed for each device, the most suitable device is then nominated as the best-matched or most suitable device for that specific location.

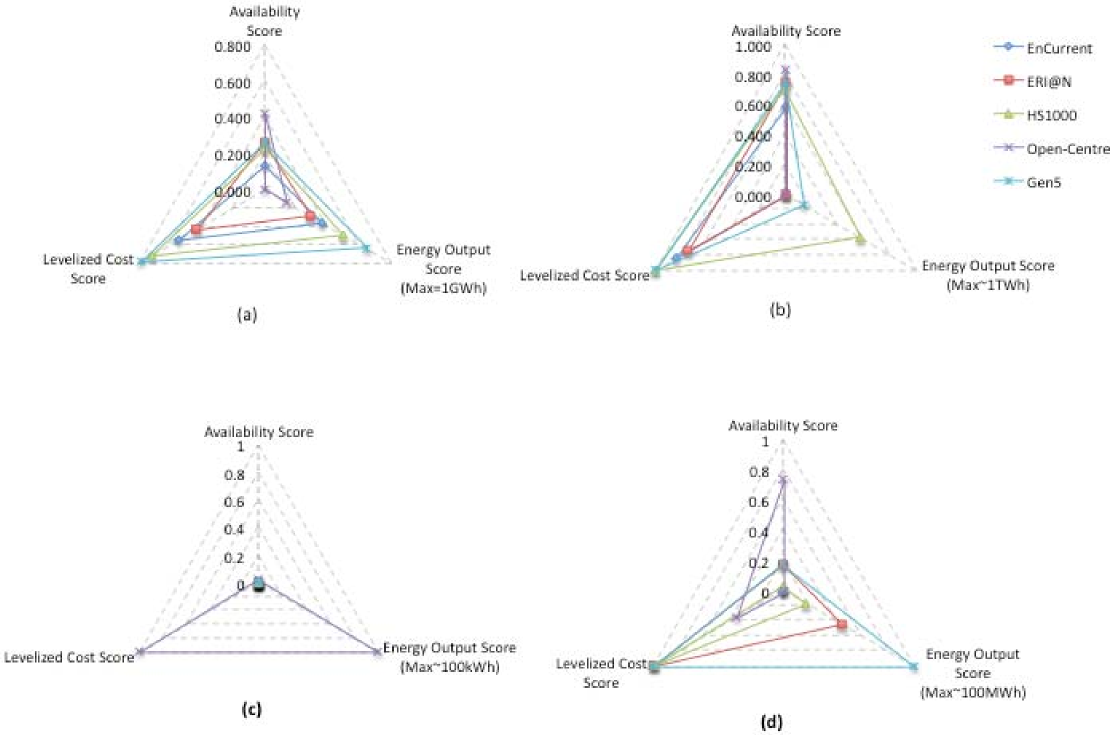

Fig. 4. Device Suitability Score Radar for Various Sites: (a) Verde; (b) Matnog; (c) Cebu; (d) Davao

4. Conclusion and Recommendations

A multiple-site and multiple-device decision support system (DSS) was developed using a combined site and device suitability framework. Site-Device matching was demonstrated for four locations in hydrodynamic-independent sites in the Philippines. Among the tidal in-stream energy conversion devices investigated for this research, Gen5 was matched with Verde and Davao, Open-Centre was matched with Cebu, while the HS1000 was matched with Matnog. Among the sites, using only the devices in this study, the feasibility ranking (from the most feasible) for tidal current power plant development is: Matnog, Verde, Davao, and Cebu.

The DSS is expandable and future work may opt to increase the number of study sites/locations and devices in the database. The framework and DSS are both flexible to accommodate other ocean renewable energy resources and technologies for as long as the necessary tweaks are done to account for nuances in each resource and for the respective extraction technologies.

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