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On

Feasibility Study of

a Novel Nearshore Wave Energy Converter

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ABSTRACT

Wave energy is a promising renewable energy source that exploits the kinetic and potential energy of waves caused by wind blowing over the ocean surface. It is advantageous over other energy sources because of its predictability, which is not affected by seasonal variations like other renewable energy sources (wind and solar).

Wave energy converters are devices engineered to extract and transform the energy of ocean waves into electricity. However, it requires specific wave characteristics, like wave height, time period, installation site, locations, etc.

In this project, a novel wave energy extraction system is proposed and studied in detail. The study focused on the comprehensive literature review of the proposed concept to verify its novelty and provide a detailed summary of the technically similar concepts available in the open literature. The summary highlights the relative advantages and disadvantages of the new system compared to other wave energy converters.

Finally, the study employs basic calculations using conventional analytical relationships to estimate output power and determine the initial dimensions of the system. The findings indicate that while the proposed system produces adequate power, this is contingent on specific conditions. Therefore, it is essential to account for location-specific design parameters and optimize their combination to maximize power extraction.

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NOMENCLATURE:

	Abbreviations		
CF	Capacity factor		
CWR	Capture width ratio		
INCOIS	Indian National Centre for Ocean Information Services		
OWC	Oscillating water column		
PTO	Power take-off		
TRL	Technology readiness level		
WEC	Wave energy converter		
	Symbols		
b	Width of terminator	P_d	Wave power density (W/m^2)
c_g	Wave front velocity (m/s)	P_{wf}	Power per meter wave front (W/m)
d	Distance b/w terminators (m)	T	Wave period (s)
d_w	Water depth (m)	t	Time (s)

E_d	Wave energy density (J/m^2)	t_1	Wall thickness (m)
F_{DW}	Net downward force (N)	T_{GEN}	Torque on the generator (N-m)
F_{up_1}	Buoyant force on terminator 1 (N)	T_{PTO}	Torque operating the PTO (N-m)
F_{up_2}	Buoyant force on terminator 2 (N)	$V_{displ.}$	Volume displaced (m^3)
g	Gravitational constant (m/s^2)	ρ_w	Seawater density (kg/m^3)
H_s	Significant wave height (m)	λ	Wavelength (m)
h	Height of terminator (m)	θ_p	Pitch angle (^{o})
h_1	Draft (m)	η	Overall efficiency
i	Gear ratio	η_{GEN}	Efficiency of generator
l	Wave front length (m)	$\eta_{gearmechanism}$	Efficiency of gear mechanism

1. INTRODUCTION

Ocean energy is one of the promising renewable energy sources; unlike other sources (solar and wind), it is not affected by seasonal variations. Its subsets include wave, tidal, ocean thermal, and marine biomass energies. Wave energy is the transportation and extraction of energy from ocean surface waves. The captured energy is subsequently used for various works, including electricity generation and water desalination. Depending on the location, it is a relatively continuous energy source and can produce power continuously, unlike wind and solar energies [1, 2].

Wave energy converters (WECs) convert the kinetic and potential energy associated with moving ocean waves into mechanical or electrical energy.

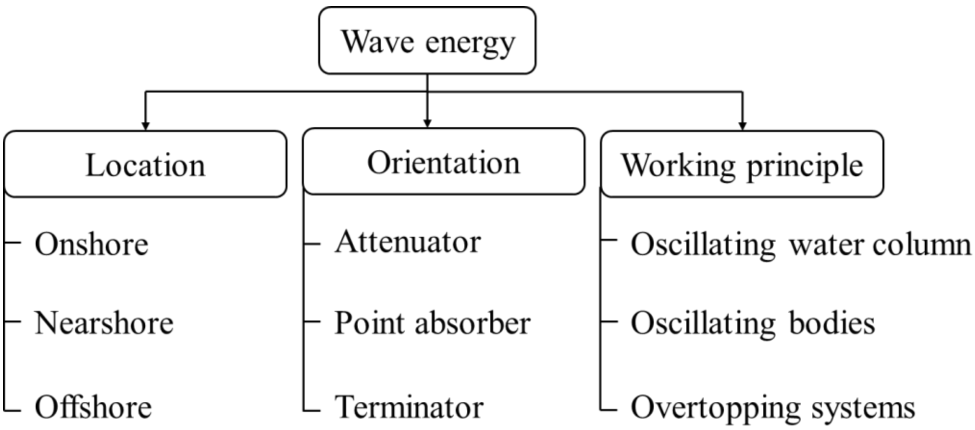


Figure 1: Types of wave energy converters.

The WECs can be installed onshore, near-shore, or deep-water locations. Bottom-found devices can work near shore or onshore locations with low water depth. In the near-shore region, the water depth varies from about half of the wavelength to one-twentieth of the wavelength [3]. Only floating devices can work if the water depth goes beyond 25 m. Ocean wave is a surface phenomenon, so any device near the water's surface will get energy from the waves.

1.1 WAVE ENERGY CALCULATION

Estimating the energy stored in the wave during conversion into electrical energy is essential. The wave energy formula can be represented by the following analysis [4].

$$E_d = \rho_w g H_s^2 / 8 \tag{1}$$

$$P_d = E_d / T = \rho_w g H_s^2 / 8T \tag{2}$$

Eq. (1) shows the energy density of wave (E_d). The energy per wave period is the density of wave power (P_d) also presented in Eq. (2).

where ρ_w is the seawater density (1025 kg/m^3), g is the gravitational constant (9.81 m/s^2), H_s indicates the significant wave height (m) and T is the wave period (s).

A wave resource is commonly defined as the power of the wavefront per meter (P_{wf}) and can be computed by multiplying the energy density with the wave celerity or wavefront velocity (c_g).

where $c_g = \frac{gT}{8\pi}$ (3)

$$P_{wf} = c_g \times E_d \quad (4)$$

Eq. (4) can be written as,

$$P_{wf} = \frac{gT}{8\pi} \times \frac{\rho_w g H_s^2}{8} = \frac{\rho_w g^2}{64\pi} H_s^2 T \frac{W}{m} \cong 0.5 H_s^2 T \frac{kW}{m} \quad (5)$$

1.2 WAVE ENERGY RESOURCES IN INDIA

India has a coastline of over 7500 km, and about 35% of its population resides within a 100 km radius of the coast [5]. The coast contains 40 GW of wave energy [6, 7] and can power in-situ communities.

Table 1 summarizes India's wave along the Indian coast. This indicates that the nation has wave potential that varies from 2 to 14 kW/m. However, the initiatives to harness this power are still being developed as they require substantial capital costs and economically suitable technology.

Table 1: Annual average value of wave conditions along the Indian coast [8].

Region	Significant wave-height H_s (m)	Mean wave-period T (s)	Power potential (kW/m)
Eastern coast	0.74 to 1.33	5.42 to 10.26	2.01 to 10.40
Western coast	1.38 to 1.44	8.55 to 9.01	10.98 to 13.70
Southern coast	1.06 to 1.49	8.26 to 9.32	6.20 to 10.91

The yearly (Jan. 1, 2023 to Dec. 31, 2023) wave data near the Indian coast in shallow water between 10 to 15 meters about 1 km off the coast for the coasts of Ratnagiri, Vizag and Pondicherry is collected from an online database ESSO-INCOIS [9].

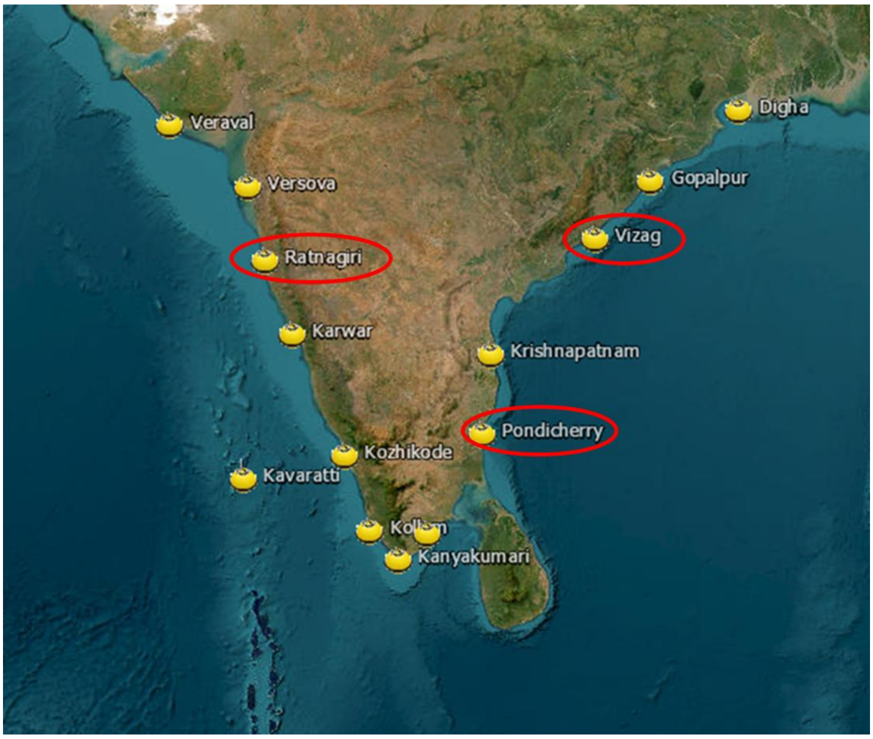


Figure 2: Location on map [9].

Yearly significant wave height and wave period for the coasts of Ratnagiri, Vizag, and Pondicherry are provided in Figures 3 and 4, respectively, so variations between the different seasons can be observed.

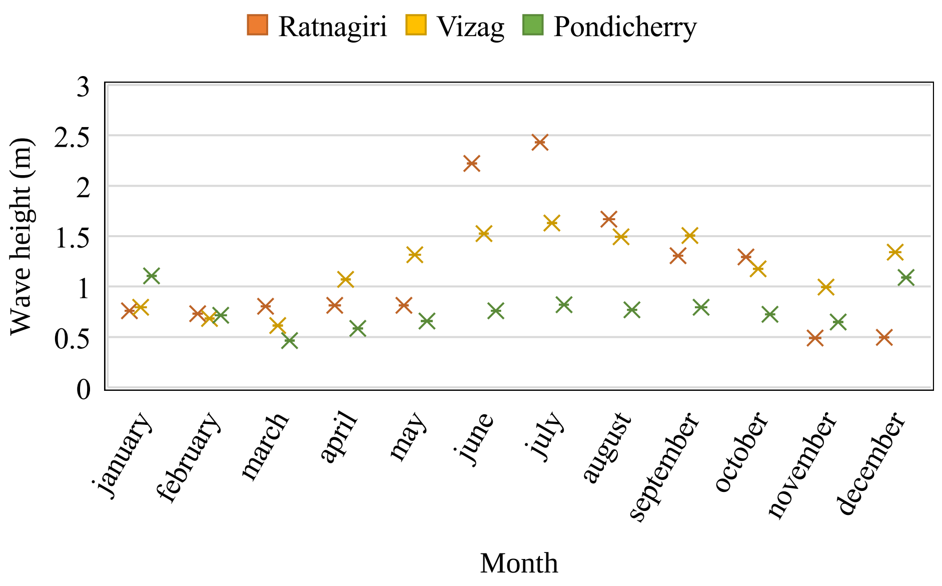


Figure 3: Significant wave height (m) as of 2023.

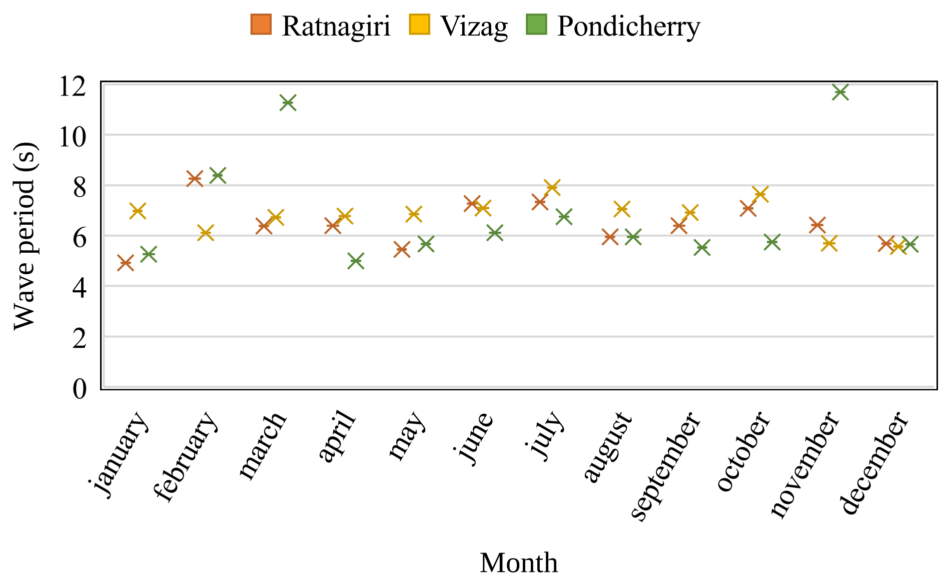


Figure 4: Wave period (s) as of 2023.

It can be observed that significant wave height varies between seasons, as predicted. While, the wave period is relatively constant for the majority of the year, with an average of 6.7 s, reaching peaks at over 8 s off Ratnagiri and Vizag about one month of the year and exceeding 11 s off Pondicherry about two months of the year.

Figure 5 depicts the average wave power available at the coasts of Ratnagiri, Vizag, and Pondicherry, which can be estimated as per Eq. (5).

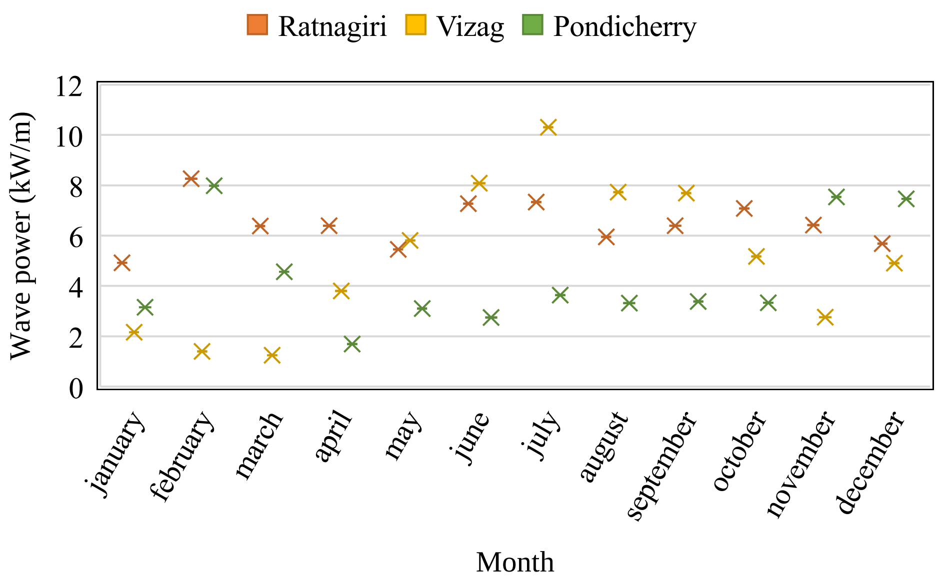


Figure 5: Wave power at (a) Ratnagiri, (b) Vizag and (c) Pondicherry as of 2023.

Based on Figure 5, comprehensive information about the average wave power at Ratnagiri, Vizag, and Pondicherry over the year 2023 is provided in Table 2.

Table 2: Annual average value of wave power.

Region	Average power potential
Ratnagiri	5.6 kW/m
Vizag	5.1 kW/m
Pondicherry	4.3 kW/m

2. WAVE HARVESTING SYSTEM

India possesses vast wave energy potential; hence, a suitable extraction method, which is also commercially viable, is needed. In this regard, this study attempts to develop a novel nearshore energy harvesting system.

2.1. PROPOSED CONCEPT

The proposed wave energy system is designed mainly for installation near the coast in shallow water ranging from as low as 1 to 10 m. Concept is most appropriate for use in waves of low intensity (5-10 kW/m) around the coast of India, as shown in schematic figure 6.

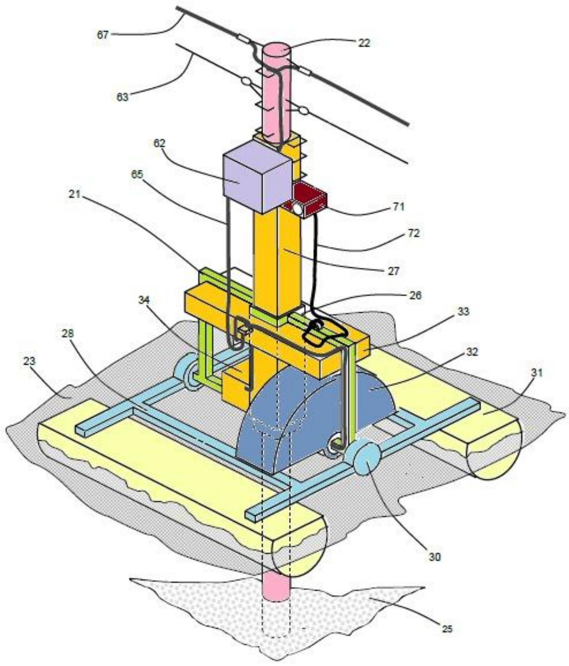


Figure 6: Monopile mounted wave energy collector.

2.1.1. Main features and advantages of the proposed concept:

- A floating type device with a low draught ideal for shallow water near the coast.
- Device can operate in depth of few meters only.
- Harnessed energy is transmitted to the power network by the use of overhead power lines, instead of costly submarine cables (cost effectively).
- Device is maintained and secured in the sea by a monopile foundation
  - require a less invasive construction,
  - cost effective,
  - easy to service.
- Able to survive harsh wave conditions by moving out of the ocean and parking safely at the top of the monopile.
- There are no underwater equipments (contributes to reduction of installation and operation cost).
- Power take-off (PTO) system comprises of equipment used in wind power systems
  - widely available off-the shelf,
  - comparatively lesser cost than PTO based on linear generators or hydraulic systems.
- Able to collect a significant amount of energy from a larger section of the wavefront.
- Low environmental impact because of a low footprint and a minimum wetted area given that most of the system is above the waterline.

However, a technical feasibility study regarding the proposed concept's power output is essential before going for a prototype model. Hence, the following objectives were proposed for this study.

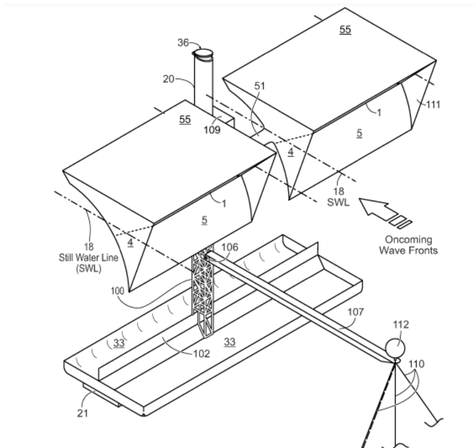
2.2. OBJECTIVE OF THE STUDY:

1. Provide a detailed summary of the technically similar concept available in the open literature.
2. Preliminary calculations for power production of proposed wave energy converter concept.
3. Provided a basic plan for the laboratory experimental.
4. Provided a comprehensive report along with the literature report and calculations.

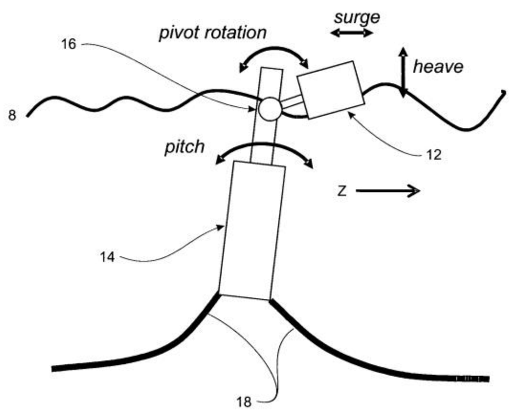
The first objective is similar to a literature review to know the similar methodology or device in the open literature. The second objective is the detailed calculation of the power extraction for a wave energy converter. These objectives are discussed in detail in the subsequent chapters.

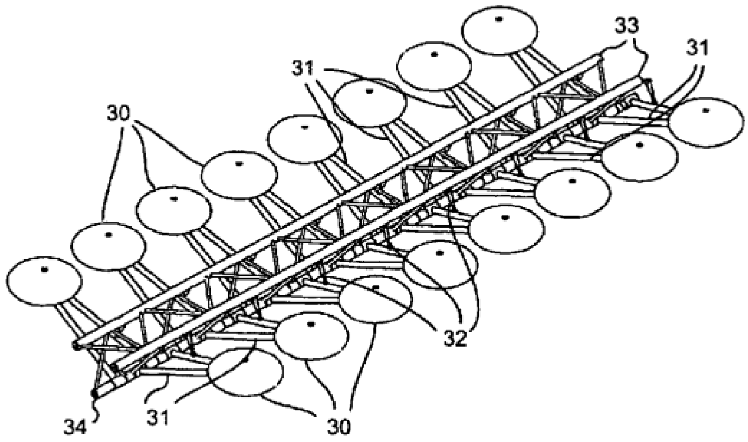
3. LITERATURE REVIEW

Based on the proposed concept, matching keyword strings such as: "pitch" "wave energy", "pitch" "wave energy converter", "pitch" "collector" "ocean energy", are used for searching documents in Google Patents and Google Scholar. The main focus was given to the patents over the journal articles to verify the novelty of the proposed concept. The device or concept with similar working principles to the proposed device found in the open literature are summarized below:

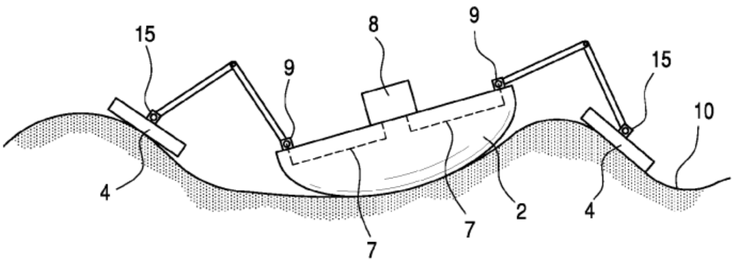
Name	High capture efficiency wave energy converter with improved heave, surge and pitch stability
Patent no	EP3790793B1 [10]
Inventor	Rohrer
Issue Year	10/01/2024
Schematic	
Remarks	The invention is used to stabilize a second reaction body or base of a multi-body WEC, which converts wave energy into electricity, against wave induced forces applied to a first or adjacent body(s)

	or floats through drive arms or hinged joints connected to a Power take-off (PTO) fixed to either body or base.

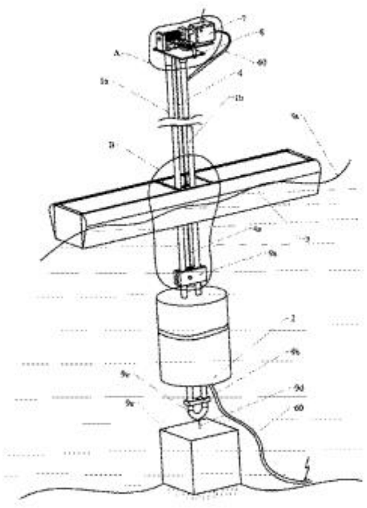
Name	Wave energy converter
Patent no	US8686582B2 [11]
Inventor	Gardiner et al.
Issue Year	01/04/2014
Schematic	
Remarks	It comprises two primary components: an active float and an elongate reactive body. The active float floats on the water surface and responds to wave motion by heaving and surging. In contrast, the reactive body is submerged and responds to wave motion by pitching. These two components are pivotably coupled, allowing to drive a power output system.

Name	Method and apparatus for converting ocean wave energy into electricity
Patent no	US8912677B2 [12]
Inventor	Dehlsen et al.
Issue Year	16/12/2014
Schematic	
Remarks	The device is anchored at both the bow and stern, positioned at a 45° angle to incoming ocean waves. It transmits power to an onshore grid via a submarine cable connected to a generator. The main body, partially submerged, consists of several pod floats that are attached to the structure through rocker arms equipped with bearings. These rocker arms guide the movement of drive tubes or are fitted with double-acting hydraulic rams positioned between the arms and the main body. Energy is captured through the displacement of the pods, which is stored in accumulators. As the pods move up and down with the wave motion, they generate

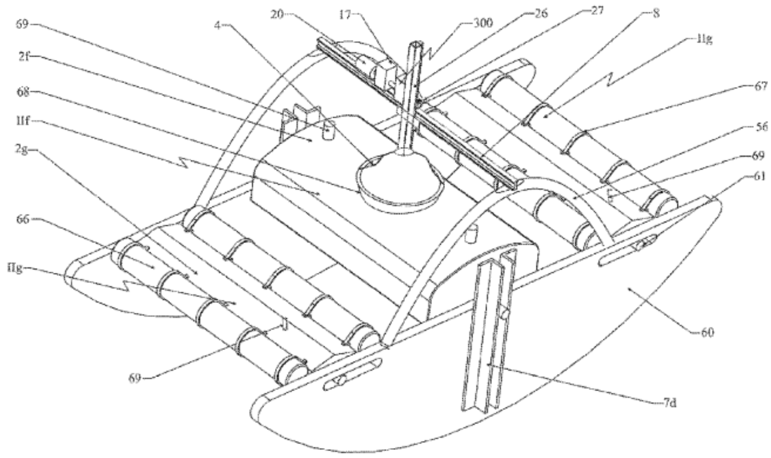
	rotary torque in the drive tubes. This torque is then transmitted to the generator to produce electricity.

Name	Wave action electric generating system
Patent no	US20180010571A1 [13]
Inventor	Werjefelt
Issue Year	11/01/2018
Schematic	
Remarks	The buoyant member rises and falls with wave action, causing the arm to move about the pivot alternately around the first shaft in a clockwise and counterclockwise motion. The buoyant member pivots at its second end in response to the waves. A first power converter captures the pivoting motion of the buoyant member to drive the electric generator, while a second power converter harnesses the arm's pivoting motion to also power the generator.

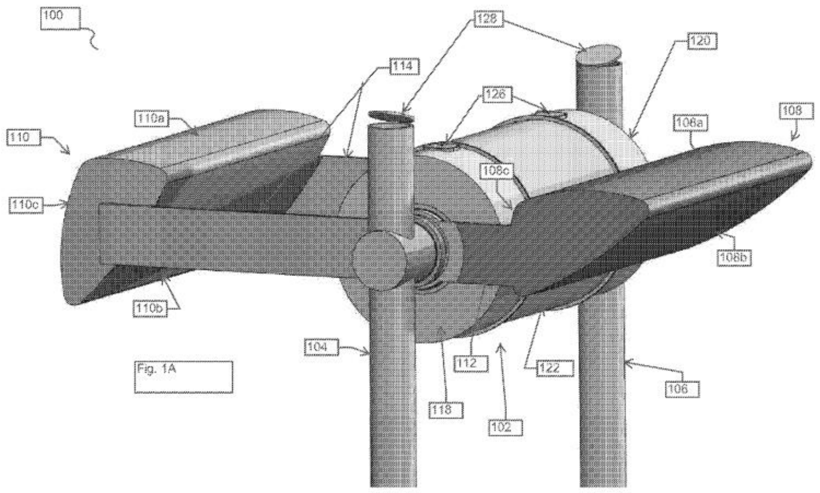
Name	Ocean wave power plant
Patent no	US10240575B2 [14]

Inventor	Dragic
Issue Year	26/03/2019
Schematic	
Remarks	An ocean wave power plant consists of a support structure anchored in the sea, featuring a lower end fastening bracket and an upper end platform supporting an electric power generating subsystem. A submergible uplift floating body provides buoyancy and is attached to the support structure. Wave motion is transferred from a floating body to the power generating subsystem via a transmission member, enabling the conversion of wave energy into electricity.

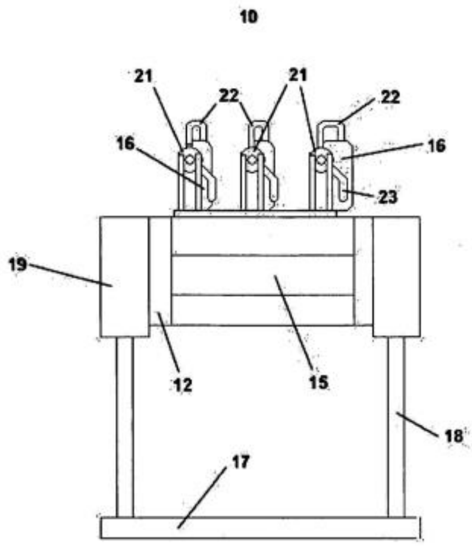
Name	System for conversion of wave energy into electrical energy
Patent no	US11125204B2 [15]
Inventor	Dragic
Issue Year	21/09/2021

Schematic	
Remarks	The floating body of the system is positioned between two or three fixed columns and moves vertically in response to wave action. A transmission shaft, either flexible or rigid, is attached to the floating body and transfers this motion to the generator for electricity production. Electrical energy can be generated using either an induction coil or a generator.

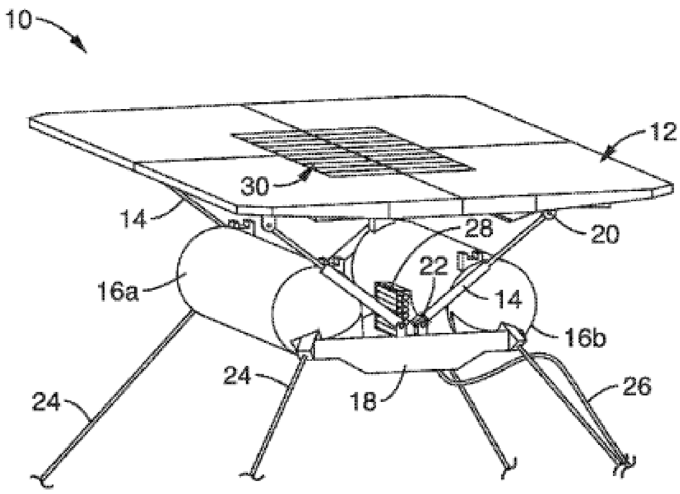
Name	Method and system for wave energy conversion
Patent no	CA2886407C [16]
Inventor	Rhinefrank et al.
Issue Year	19/02/2019

Schematic	
Remarks	This invention pertains to the conversion of wave surge and heave into energy. It describes an apparatus and method for harnessing wave energy through the relative rotational movement between two interconnected float assemblies, as well as between each float assembly and a spar. The spar extends from a buoyant nacelle along its central longitudinal axis, with the floats designed to nest behind the nacelle.

Name	System and method for renewable electrical power production using wave energy
Patent no	KR20130137118A [17]
Inventor	Cunningham and Molly
Issue Year	16/12/2013

Schematic	
Remarks	Wave-coupled front and rear barges are connected to a central inertial barge by hinges, allowing for joint motion. A damper plate is attached to the central barge to reduce its heaving motion, thereby enhancing stability. The concentrated weight of the plate, supported by side swabs, generates a pendulum effect that induces pitching motion in the central barge, improving the relative angular movement between the barges. An energy conversion device is operatively linked to the front, rear, and central barges to collect and convert energy from the relative wave-induced motions and displacements of the front and rear barges with respect to the central barge.

Name	Submerged wave energy converter for shallow and deep water operations

Patent no	US10767618B2 [18]
Inventor	Lehmann et al.
Issue Year	08/09/2020
Schematic	
Remarks	A submerged wave energy conversion system is designed to generate pressurized fluid or electricity by harnessing energy from pressure differentials created through its interaction with ocean water. The system can capture energy from up to six modes of motion exhibited by the absorber body in response to incoming waves. The absorber is connected to one or more damping mechanisms, such as hydraulic cylinders, which drive a hydraulic circuit to generate useful mechanical torque. A restoring mechanism, like an air spring, brings the absorber back to stable equilibrium, while a buoyant artificial floor provides the necessary opposing reaction force. Additionally, the system may include a controller for real-time monitoring and optimization of energy

	extraction, as well as load management to prevent excessive loads that could damage the system.

Table 3: Relative merit among wave energy converter systems.

Wave energy systems	Present invention	Point absorber (floating & heave)	Oscillating water column (Fixed)	Oscillating water column (Floating)	Oscillating wave surge (bottom hinged & rotation i.e., pitching motion)	Attenuator (floating & rotation i.e., pitch)	Overtopping device	Terminator (floating)	Submerged Pressure differential (heave)
Type of converters [19 – 26]	Monopile-mounted wave energy collector	AquaBuoy, Ceto (Carnegie), Lysekil Wave Energy Site, PowerBuoy, Wavebob, Wave star, Azura, SINN Power, CorPower, EcoWave power, Neptune	Mutriku, Sakata, Pico plant, LIMPET	Ocenlix, OE buoy, Sperboy, mighty whale	Oyster, WaveRoller/AW-Energy	Pelamis, SEAREV, Salter Duck	Wave Dragon	Salter's Duck	Archimedes Wave Swing (AWS)
Installed Capacity [25 – 33]	5 – 10 kW/m	1 MW (Carnegie Wave); 30 kW (Lysekil); 20 kW (Azura); 3 kW (OPT PowerBuoy); 0.72 MW (Ceto5); 4 MW (Ceto6); 2 kW (SINN Power), 300 kW (CorPower), 45 kW (PowerBuoy), 250	300 kW (Mutriku)	1.25 MW (OE35); 500 kW (OE)	350 kW (WaveRoller)	750 kW (Pelamis)	1.5 – 12 MW	NA	1.5 MW

		kW (Aqua Buoy); 2.3 MW (Neptune)							
Installation difficulty	Moderate, requires precise construction of foundation	Medium to High, depending on depth and anchoring system. Installation is relatively straightforward but still requires careful planning and execution to withstand the largest storm waves	High, requires precise construction	High, requires precise mooring and seabed foundation	High, requires local geotechnical seabed conditions and underwater mooring along with submersible underwater cable	High; requires deep-water deployment and mooring systems also includes submersible underwater cable; requires local geotechnical seabed conditions	Medium, use the existing breakwaters	Medium to High, depending on depth and anchoring system	High, requires local geotechnical seabed conditions
Power extraction	Moderate; suitable for a low-energy waves converting wave energy to mechani	Moderate; suitable for a wide range of wave heights to convert wave energy to mechanical/ hydraulic energy	Moderate to high; converting wave energy into air pressure output is dependent on the level of wave energy, which varies day by day	High; wave-to-pneumatic energy conversion	Moderate to high; suitable for medium energy wave environments	High; suitable for high-energy wave environments	Low to moderate; captures the movements of the tides and waves and converts it into potential energy	Low to moderate	High

	cal energy		according to the season						
Technolog y readiness [28, 34]	TRL 2	TRL 7 (SINN Power; Carnegie; OPT; Eco Wave Power)	TRL 8	TRL 7 (OE)	TRL 7 (WaveRoller)	TRL 8	TRL 7	TRL 7	TRL 6 (only attempted but not achieved)
Levelized Cost of Energy [34]	–	Variable depends on scale, location, and technology used. High CAPEX due to mooring but can be cost-effective in suitable locations. The greater amount of energy available in deep water could still make it more structurally efficient (MWh/ton) than nearshore devices.	High CAPEX, no ready supply chains, and few standardized components are available	High CAPEX and OPEX	Initial installation, R&D costs as well as manufacturing costs are high.	Relatively high; demonstrated reliability but faced economic challenges; economies of scale needed to reduce costs	R&D and installation costs are high	Manufac turing and installati on costs are high	High operation costs due to remotenes s
Environm ent	low visual impact and low environ	typically has the lowest environmental impact	largest visual and environmenta l impact due to the	Minimal impact; some noise concerns	Low impact	Low impact; design minimizes	Low impact but may harm to marine life	Low impact; environ	Low impact but may harm marine life

	mental impact		location on land and by reducing the natural coastline habitat	from turbines		harm to marine life		mentally friendly	
Extreme forces	Good. adaptive	Good. Adaptive, allows for some flexibility and adjustment to extreme weather conditions	Generally resilient; design can mitigate extreme weather impacts	NA	Good. adaptive	Good adaptation to extreme forces due to articulated segments	NA	NA	NA
Tidal variation	Good, adaptive	Adaptive to tidal variation due to vertical motion	Moderate impact; performance can vary with water level changes	NA	NA	Moderate impact; performance can vary with tide	Adaptive	NA	Impacted by tidal variation
Cost of installatio n	Dependi ng on how close to land the device is located it may benefit	High due to mooring systems	High due to complex construction and civil works	Civil construction dominates the cost of the OWC plant	NA	High; offshore deployment adds to costs	Moderate to high due to slack moored floating structure	NA	High due to complex mooring systems and need of long underwate

	from easier grid connection								r electrical cables
Low energy (5-10 kW/m) [19, 20, 22, 26, 27, 29]	Efficient; works well in low energy environments	Suitable for high energy waves.	Less efficient; better in higher energy locations	NA	NA	Less efficient; designed for high-energy environments	NA	NA	NA
Nearshore application [19-21, 35-37]	Suitable for nearshore (water depth: < 30 m)	Bottom mounted suitable for nearshore location else located at offshore environments, sensitive to mooring system design AquaBuoy & WaveBob deployed where water depth is greater than 50 m. Eco Wave Power deployed at	installed in shoreline locations onto or near to rocks or cliffs, can be integrated into breakwaters or coastal structures	Often installed in nearshore locations	Nearshore in relatively shallow water depth (10–15 m)	Typically, offshore, not ideal for nearshore	Offshore converter	Offshore	exploit the more powerful wave regimes available in deep water (typically more than 40 m water depth)

		nearshore and onshore locations.							
PTO [19, 26, 36, 37]	Single stage gearbox	Hydraulic PTO, Linear generator	Air turbine	Air turbine	Hydraulic, Linear generator	Hydraulic PTO	Low-head hydraulic turbine usually Kaplan turbine	Hydraulic PTO	Linear electrical generator
Repair/maintenance	easily accessible for maintenance and for grid connection	Maintenance can be difficult in the offshore location if it is heavily dependent on weather windows with a high transit time to site and transmission costs may be higher for offshore sites as it will be further from a grid connection.	Turbine can be easily removed for repair or maintenance	NA	Maintenance is more challenging than shoreline devices but some nearshore devices compensate for this by locating some of their PTO onshore. Oyster pumps high pressure sea water onshore to drive a Pelton wheel	NA	NA	NA	NA

3.1. THE PROS AND CONS OF THE PROPOSED WAVE ENERGY CONVERTER SYSTEM

Pros:

- *Efficient Nearshore Application*: Ideal for nearshore deployment, and making it easier to access for maintenance and grid connection. This makes it particularly suitable for coastal and island communities that require reliable and localized energy sources.
- *Moderate Power Extraction*: Effective in low to medium energy wave environments, making it viable for areas with less intense wave activity.
- *Lower Installation Costs*: Installation is generally more affordable compared to offshore systems, as it avoids the need for complex deep-water mooring and long underwater cables by using a monopile-mounted structure and overhead power transmission lines.
- *Reduced Operational Costs*: Maintenance and operation are more convenient and less costly due to proximity to land, reducing transit times and weather dependencies. Additionally, their connection to the electrical network is cheaper because shorter electrical cables are required.
- *Good Adaptation to Extreme Forces*: Resilient design that adapts to extreme weather conditions and tidal variations, with the ability to park above waves during extreme conditions, enhancing the reliability and durability of the system.
- *Utility for Island Communities*: a cost-effective and sustainable alternative to diesel generators for island communities, contributing to reduce the reliance on fossil fuels and promoting the adoption of renewable energy.

Cons:

- *Limited Energy Potential*: Nearshore environments typically have lower wave energy compared to offshore sites, limiting the overall power output potential.
- *Site selection*: Requires careful site selection and potential adjustments in positioning and ensuring the direction of incoming wave alignment.
- *Environmental Impact*: Nearshore installations can impact coastal ecosystems and disrupt natural habitats and sediment transport more directly compared to offshore systems.
- *Variable Power Output*: Performance is contingent on wave conditions, which can fluctuate significantly, affecting energy generation and require integration with energy storage systems to stabilize output.

The proposed WEC system offers significant advantages in terms of cost, adaptability, and scalability for nearshore applications. However, site selection and environmental impact to natural habitats remain challenges. By addressing these limitations through advanced design and optimized site selection, it can serve as a competitive alternative to existing WECs.

4. NUMERICAL CALCULATIONS

The proposed wave energy system illustrated in Figure 4 is considered for further calculation.

4.1. ESTIMATION OF WAVE FORCE ON TERMINATOR

Estimating the force experienced by a terminator in the ocean is not straightforward as it also experiences a range of forces like wave, tide, and wind load. However, for simple cases, the following assumptions are made during calculation.

1. Tidal and wind loads are neglected
2. The wave variation is similar to harmonic motion, where the seawater rises and falls.

Consider a simple force balance diagram (Figure 7). Here, the wave force acts on the terminator, and the gravitational force acts downward. However, the terminator remains floating and experiences a buoyance force equal to the volume of fluid displaced.

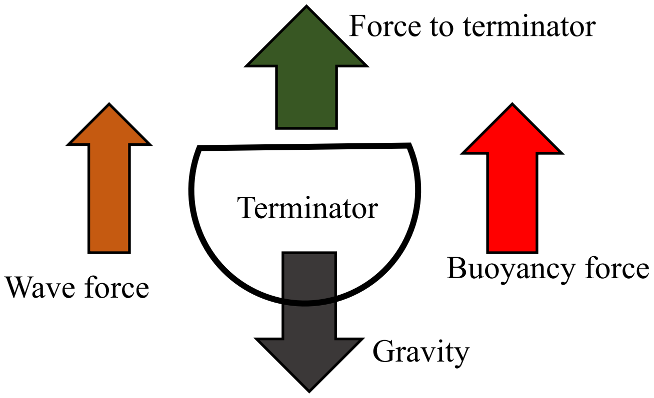


Figure 7: Force balance of the terminator.

The net force experienced by the terminator = Wave Force + Buoyancy force – Gravitational force

Breakup the individual components of force as follows:

1. Buoyancy force = volume of water displaced* density * g
2. Gravity force = mass of terminator * g = volume of terminator * density * g

The volume of water displaced can be estimated as Eq. (6), given below:

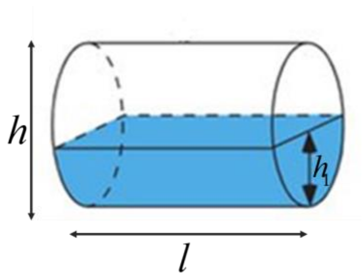


Figure 8: Schematic diagram of a floating horizontal cylinder.

$$V_{displ.} = \left[\left(\sqrt{h_1 h - h_1^2} \right) \left(\frac{h}{2} - h_1 \right) + \left(\frac{h}{2} \right)^2 \left(\pi - \cos^{-1} \left(\frac{2h_1 - h}{h} \right) \right) \right] \times l \tag{6}$$

The forces necessary to generate the torque on the generator are shown in Figure 8. It is provided by the resultant buoyant force F_{UP_1} and F_{UP_2} due to both terminators and the downward force F_{DW}. F_{DW} is the combined weight of the whole nacelle, including the ballast water.

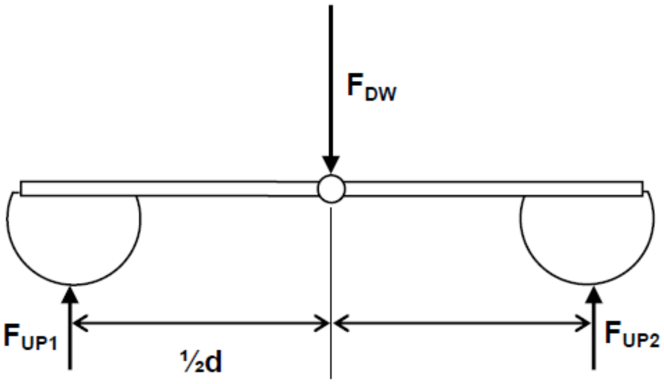


Figure 9: Main forces operating the PTO.

The individual components of force as follows:

1. Downward force (F_{DW}) = weight of nacelle + weight of water ballast
2. Weight of water ballast = volume of water inside the ballast * density * g

In static condition,

$$\mathrm{F_{DW}} = \mathrm{F_{UP_1}} + \mathrm{F_{UP_2}}$$

(7)

$$\mathrm{T_{PTO}} = (\mathrm{F_{UP_1}} \text{-} \mathrm{F_{UP_2}}) \times \frac{1}{2} d \times \mathrm{Cos}\,\theta_p \tag{8}$$

$$\mathrm{T_{GEN}} = \mathrm{T_{PTO}} / i \tag{9}$$

$$\mathrm{P_{GEN}} = \mathrm{T_{GEN}} \times (d\theta_p / dt) \times \eta \tag{10}$$

where T_{PTO} is the torque operating the PTO, T_{GEN} is the torque on the generator, θ_p represents the pitch angle of the platform, i denotes the gear ratio and η indicates the overall efficiency of the generator and gear mechanism that can be estimated by Eq. (11).

$$\eta = \eta_{GEN} \times \eta_{gearmechanism} \tag{11}$$

The spacing between both the terminators is denoted by d and the optimum distance should be half of the distance between succeeding wavefronts (wavelength, λ), or less $\left(d \leq \lambda/2\right)$

where $\lambda = \frac{gT^2}{2\pi}\tanh\left(\frac{2\pi d_w}{\lambda}\right)$ (12)

For shallow water approximation, wavelength can be expressed as Eq. (13).

$$\lambda = \sqrt{gd_w} \times T \tag{13}$$

where d_w denotes the water depth and it is considered as 2 m for the preliminary calculation.

Capacity factor (CF): The capacity factor (CF) is calculated by dividing the average power output by the maximum possible output. The maximum possible output is the theoretical maximum energy that would be produced if the WEC operated at full nameplate capacity for the entire period.

Capture width ratio (CWR): The capture width ratio is a measure of how efficiently a WEC converts wave energy into power. It's calculated by dividing the average power generated by the WEC by the wave power resource.

The detailed results of the preliminary calculations and power absorption analysis of a proposed WEC system across various conditions is listed in Table 5. The calculations take into account wave parameters, gear ratios, and capacity factor for different wave periods (T) and heights (H). Moreover, Table 6, 7 and 8 provide the key insights include the relationship between wave height, the WEC's power absorption capacity, and how gear ratios and spacing between the floaters influence the performance of the system.

Table 5: Preliminary calculation for the proposed wave energy converter system.

Wave period, T (s)	Wave length, λ (m)	Distance b/w both floaters, d=λ/2 (m)	Wave front length, l (m)	Width of terminator, b (m)	Depth of terminator, h (m)	Draft, h_1 (m)	Wall thickness (m)	Vol. of floater (m^3)	Displaced volume (m^3)	Buoyancy force (N)	Mass of Nacelle (kg)	Wt. of Nacelle (N)	Wt. of water in ballast (N)
5	22.15	11.07	5	2	1	0.6	0.005	7.854	7.629	153432	500	4905	148527
6	26.58	13.29	5	2	1	0.6	0.005	7.854	7.629	153432	500	4905	148527
7	31.01	15.50	5	2	1	0.6	0.005	7.854	7.629	153432	500	4905	148527
8	35.44	17.72	5	2	1	0.6	0.005	7.854	7.629	153432	500	4905	148527
9	39.87	19.93	5	2	1	0.6	0.005	7.854	7.629	153432	500	4905	148527

For T = 5 s, λ = 22.15 m, d = 11.07 m, θ_p = 45°, gear ratio (i) = 8, gen. eff. = 0.8, gear mechanism eff. = 0.9, eff. (η) = 0.72, CF = 0.25

Wave height, H (m)	Energy in the wave, E_d (kW/m)	WEC max energy absorbs, E_{max} (W)	Relative motion, assumed 80% of wave height (m)	WEC force, F_{wec} (N)	normal distance of floater to pivot = (d/2)*cos(θ_p)	Torque_PTO, Tpto (N-m)	Generator torque_Tgen (N-m)	Gen. power_Pgen (W)	Power absorbed (W)	Capture width ratio (%)
0.2	0.10	500	0.16	15625	3.92	61174	7647	3459	865	173
0.3	0.23	1125	0.24	23438	3.92	91761	11470	5189	1297	115
0.5	0.63	3125	0.40	39063	3.92	152934	19117	8648	2162	69
0.7	1.23	6125	0.56	54688	3.92	214108	26763	12108	3027	49
1	2.50	12500	0.80	78125	3.92	305868	38234	17296	4324	35
1.5	5.63	28125	1.20	117188	3.92	458803	57350	25945	6486	23
2	10.00	50000	1.60	156250	3.92	611737	76467	34593	8648	17
2.5	15.63	78125	2.00	195313	3.92	764671	95584	43241	10810	14

For T = 6 s, λ = 26.58 m, d = 13.29 m, θ_p = 45°, gear ratio (i) = 8, gen. eff. = 0.8, gear mechanism eff. = 0.9, eff. (η) = 0.72, CF = 0.25

Wave height, H (m)	Energy in the wave, E_d (kW/m)	WEC max energy absorbs, E_{max} (W)	Relative motion, assumed 80% of wave height (m)	WEC force, F_{wec} (N)	normal distance of floater to pivot = (d/2)*cos(θ_p)	Torque_PTO, Tpto (N-m)	Generator torque_Tgen (N-m)	Gen. power_Pgen (W)	Power absorbed (W)	Capture width ratio (%)
0.2	0.12	600	0.16	22500	4.70	105708	13214	4981	1245	208
0.3	0.27	1350	0.24	33750	4.70	158562	19820	7472	1868	138
0.5	0.75	3750	0.40	56250	4.70	264270	33034	12453	3113	83
0.7	1.47	7350	0.56	78750	4.70	369978	46247	17435	4359	59
1	3.00	15000	0.80	112500	4.70	528541	66068	24907	6227	42
1.5	6.75	33750	1.20	168750	4.70	792811	99101	37360	9340	28
2	12.00	60000	1.60	225000	4.70	1057081	132135	49814	12453	21
2.5	18.75	93750	2.00	281250	4.70	1321351	165169	62267	15567	17

For T = 7 s, λ = 31.01 m, d = 15.50 m, θ_p = 45°, gear ratio (i) = 8, gen. eff. = 0.8, gear mechanism eff. = 0.9, eff. (η) = 0.72, CF = 0.25

Wave height, H (m)	Energy in the wave, E_d (kW/m)	WEC max energy absorbs, E_{max} (W)	Relative motion, assumed 80% of wave height (m)	WEC force, F_{wec} (N)	normal distance of floater to pivot = (d/2)*cos(θ_p)	Torque_PTO, Tpto (N-m)	Generator torque_Tgen (N-m)	Gen. power_Pgen (W)	Power absorbed (W)	Capture width ratio (%)
0.2	0.14	700	0.16	30625	5.48	167861	20983	6780	1695	242
0.3	0.32	1575	0.24	45938	5.48	251791	31474	10170	2543	161
0.5	0.88	4375	0.40	76563	5.48	419651	52456	16951	4238	97
0.7	1.72	8575	0.56	107188	5.48	587512	73439	23731	5933	69
1	3.50	17500	0.80	153125	5.48	839303	104913	33901	8475	48
1.5	7.88	39375	1.20	229688	5.48	1258954	157369	50852	12713	32
2	14.00	70000	1.60	306250	5.48	1678606	209826	67802	16951	24
2.5	21.88	109375	2.00	382813	5.48	2098257	262282	84753	21188	19

For T = 8 s, λ = 35.44 m, d = 17.72 m, θ_p = 45°, gear ratio (i) = 8, gen. eff. = 0.8, gear mechanism eff. = 0.9, eff. (η) = 0.72, CF = 0.25

Wave height, H (m)	Energy in the wave, E_d (kW/m)	WEC max energy absorbs, E_{max} (W)	Relative motion, assumed 80% of wave height (m)	WEC force, F_{wec} (N)	normal distance of floater to pivot = (d/2)*cos(θ_p)	Torque_PTO, Tpto (N-m)	Generator torque_Tgen (N-m)	Gen. power_Pgen (W)	Power absorbed (W)	Capture width ratio (%)
0.2	0.16	800	0.16	40000	6.26	250567	31321	8856	2214	277
0.3	0.36	1800	0.24	60000	6.26	375851	46981	13284	3321	184
0.5	1.00	5000	0.40	100000	6.26	626418	78302	22139	5535	111
0.7	1.96	9800	0.56	140000	6.26	876986	109623	30995	7749	79
1	4.00	20000	0.80	200000	6.26	1252837	156605	44279	11070	55
1.5	9.00	45000	1.20	300000	6.26	1879255	234907	66418	16605	37
2	16.00	80000	1.60	400000	6.26	2505674	313209	88558	22139	28
2.5	25.00	125000	2.00	500000	6.26	3132092	391511	110697	27674	22

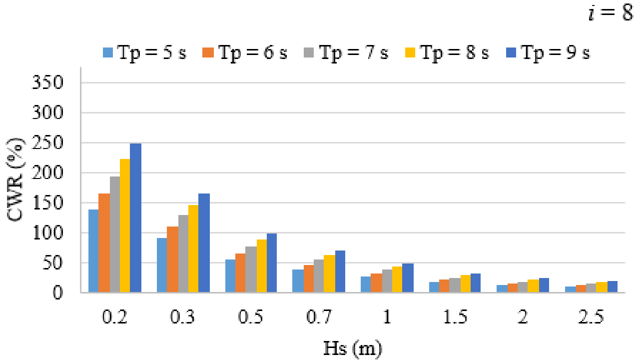
For T = 9 s, λ = 39.87 m, d = 19.93 m, θ_p = 45°, gear ratio (i) = 8, gen. eff. = 0.8, gear mechanism eff. = 0.9, eff. (η) = 0.72, CF = 0.25

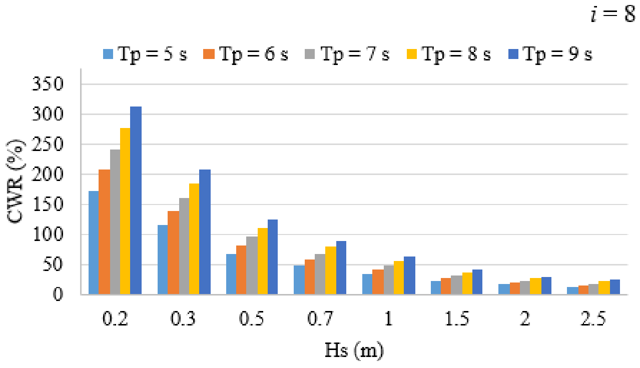
Wave height, H (m)	Energy in the wave, E_d (kW/m)	WEC max energy absorbs, E_{max} (W)	Relative motion, assumed 80% of wave height (m)	WEC force, F_{wec} (N)	normal distance of floater to pivot = (d/2)*cos(θ_p)	Torque_PTO, Tpto (N-m)	Generator torque_Tgen (N-m)	Gen. power_Pgen (W)	Power absorbed (W)	Capture width ratio (%)
0.2	0.18	900	0.16	50625	7.05	356765	44596	11208	2802	311
0.3	0.41	2025	0.24	75938	7.05	535147	66893	16812	4203	208
0.5	1.13	5625	0.40	126563	7.05	891912	111489	28020	7005	125
0.7	2.21	11025	0.56	177188	7.05	1248677	156085	39228	9807	89
1	4.50	22500	0.80	253125	7.05	1783824	222978	56040	14010	62
1.5	10.13	50625	1.20	379688	7.05	2675736	334467	84061	21015	42
2	18.00	90000	1.60	506250	7.05	3567648	445956	112081	28020	31
2.5	28.13	140625	2.00	632813	7.05	4459561	557445	140101	35025	25

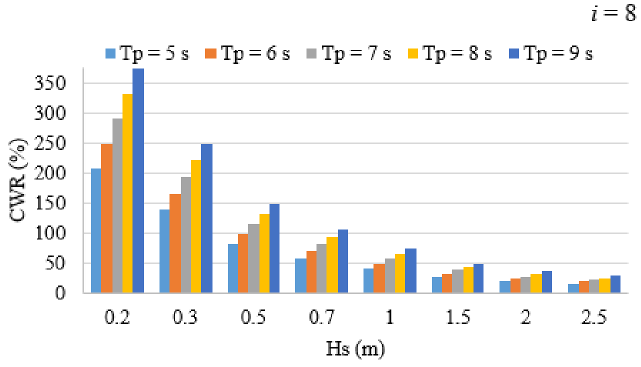
Table 6: Calculation for optimal power absorption condition ($d = \lambda/2$).

Gear ratio	CF = 0.20	CF = 0.25	CF = 0.30

$i = 8$







CF = 0.20

Hs/Tp	5	6	7	8	9
0.2	138	166	194	221	249
0.3	92	111	129	148	166
0.5	55	66	77	89	100
0.7	40	47	55	63	71
1	28	33	39	44	50
1.5	18	22	26	30	33
2	14	17	19	22	25
2.5	11	13	15	18	20

CF = 0.25

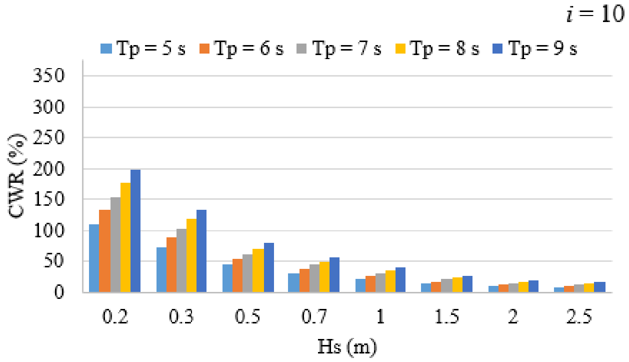
Hs/Tp	5	6	7	8	9
0.2	173	208	242	277	311
0.3	115	138	161	184	208
0.5	69	83	97	111	125
0.7	49	59	69	79	89
1	35	42	48	55	62
1.5	23	28	32	37	42
2	17	21	24	28	31
2.5	14	17	19	22	25

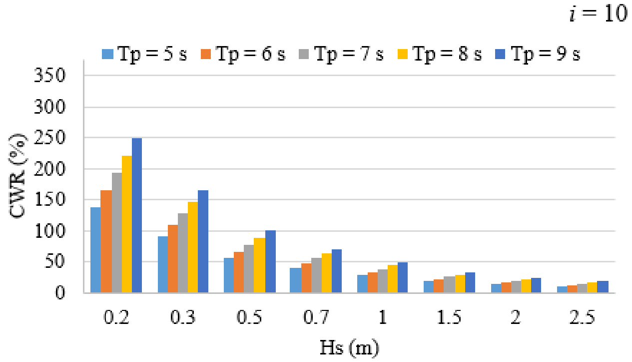
CF = 0.30

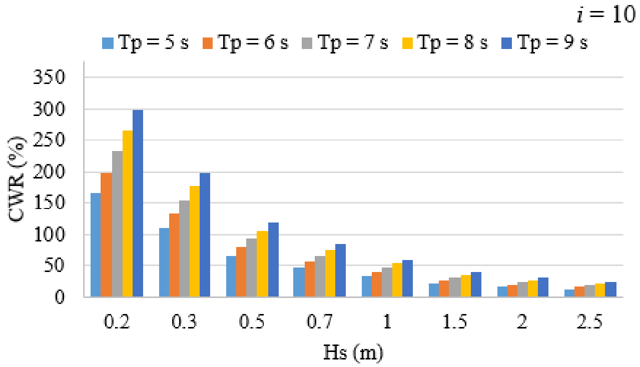
Hs/Tp	5	6	7	8	9
0.2	208	249	291	332	374
0.3	138	166	194	221	249
0.5	83	100	116	133	149
0.7	59	71	83	95	107
1	42	50	58	66	75
1.5	28	33	39	44	50
2	21	25	29	33	37
2.5	17	20	23	27	30

Note: The data in green color can be considered as a feasible condition.

i = 10





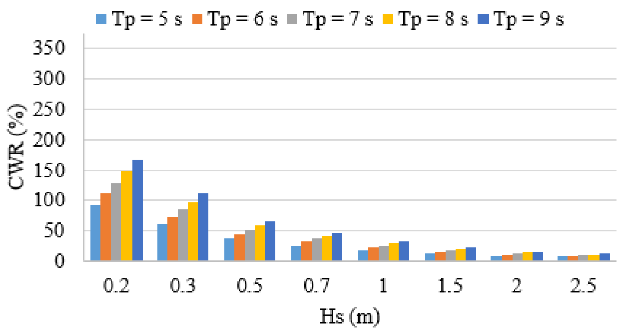


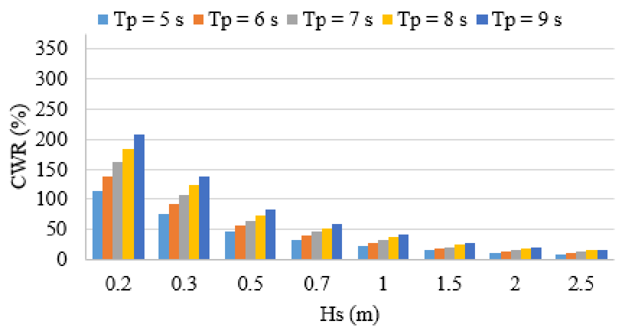
Hs/Tp	5	6	7	8	9
0.2	111	133	155	177	199
0.3	74	89	103	118	133
0.5	44	53	62	71	80
0.7	32	38	44	51	57
1	22	27	31	35	40
1.5	15	18	21	24	27
2	11	13	15	18	20
2.5	9	11	12	14	16

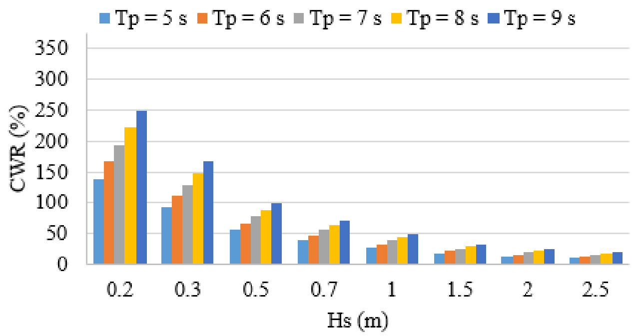
Hs/Tp	5	6	7	8	9
0.2	138	166	194	221	249
0.3	92	111	129	148	166
0.5	55	66	77	89	100
0.7	40	47	55	63	71
1	28	33	39	44	50
1.5	18	22	26	30	33
2	14	17	19	22	25
2.5	11	13	15	18	20

Hs/Tp	5	6	7	8	9
0.2	166	199	232	266	299
0.3	111	133	155	177	199
0.5	66	80	93	106	120
0.7	47	57	66	76	85
1	33	40	46	53	60
1.5	22	27	31	35	40
2	17	20	23	27	30
2.5	13	16	19	21	24

$i = 12$ $i = 12$ $i = 12$ $i = 12$







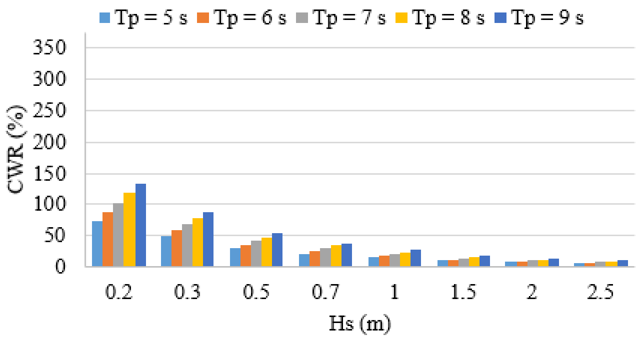
Hs/Tp	5	6	7	8	9
0.2	92	111	129	148	166
0.3	61	74	86	98	111
0.5	37	44	52	59	66
0.7	26	32	37	42	47
1	18	22	26	30	33
1.5	12	15	17	20	22
2	9	11	13	15	17
2.5	7	9	10	12	13

Hs/Tp	5	6	7	8	9
0.2	115	138	161	184	208
0.3	77	92	108	123	138
0.5	46	55	65	74	83
0.7	33	40	46	53	59
1	23	28	32	37	42
1.5	15	18	22	25	28
2	12	14	16	18	21
2.5	9	11	13	15	17

Hs/Tp	5	6	7	8	9
0.2	138	166	194	221	249
0.3	92	111	129	148	166
0.5	55	66	77	89	100
0.7	40	47	55	63	71
1	28	33	39	44	50
1.5	18	22	26	30	33
2	14	17	19	22	25
2.5	11	13	15	18	20

$i = 15$

$i = 15$



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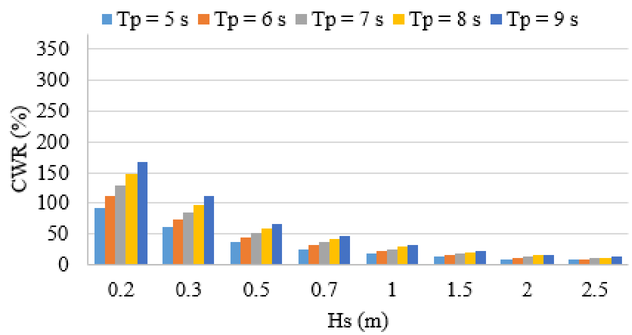

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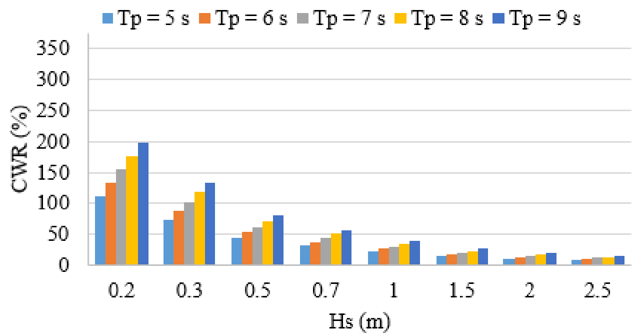
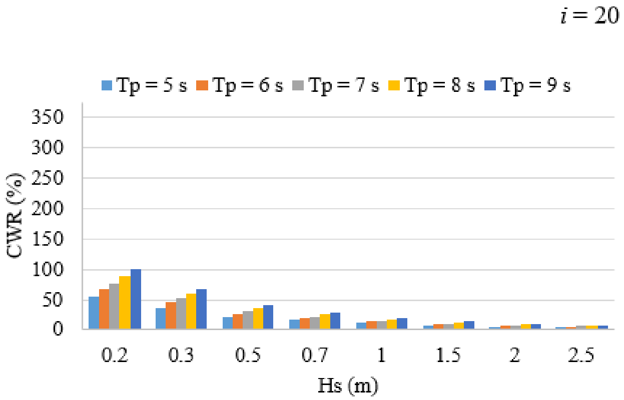


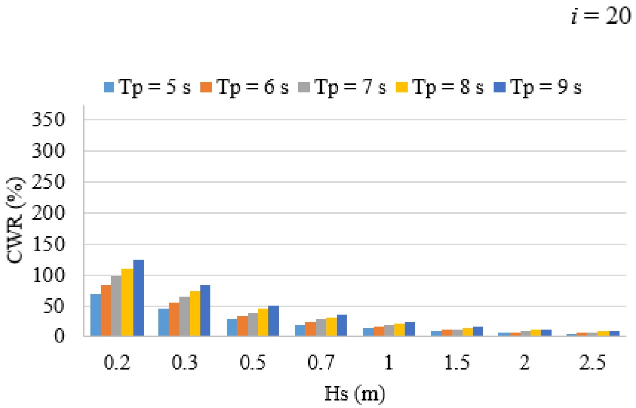
Hs/Tp	5	6	7	8	9
0.2	74	89	103	118	133
0.3	49	59	69	79	89
0.5	30	35	41	47	53
0.7	21	25	30	34	38
1	15	18	21	24	27
1.5	10	12	14	16	18
2	7	9	10	12	13
2.5	6	7	8	9	11

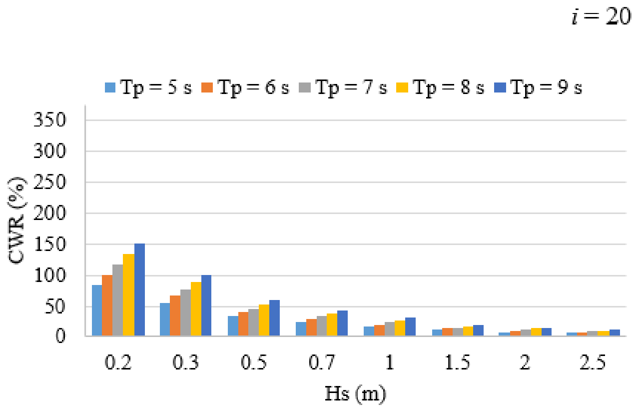
Hs/Tp	5	6	7	8	9
0.2	92	111	129	148	166
0.3	61	74	86	98	111
0.5	37	44	52	59	66
0.7	26	32	37	42	47
1	18	22	26	30	33
1.5	12	15	17	20	22
2	9	11	13	15	17
2.5	7	9	10	12	13

Hs/Tp	5	6	7	8	9
0.2	111	133	155	177	199
0.3	74	89	103	118	133
0.5	44	53	62	71	80
0.7	32	38	44	51	57
1	22	27	31	35	40
1.5	15	18	21	24	27
2	11	13	15	18	20
2.5	9	11	12	14	16

$i = 20$





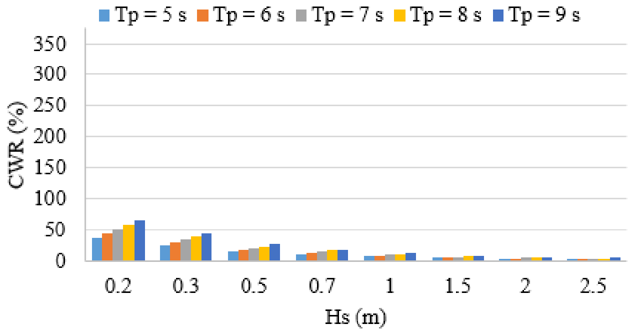


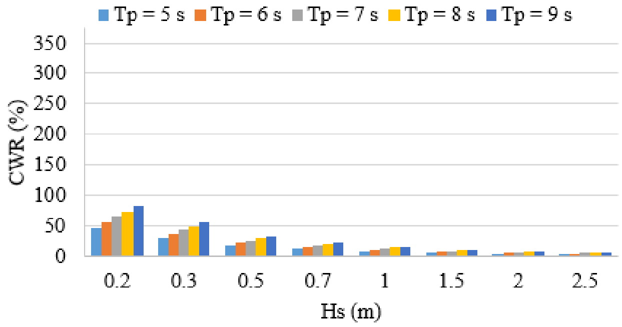
Hs/Tp	5	6	7	8	9
0.2	55	66	77	89	100
0.3	37	44	52	59	66
0.5	22	27	31	35	40
0.7	16	19	22	25	28
1	11	13	15	18	20
1.5	7	9	10	12	13
2	6	7	8	9	10
2.5	4	5	6	7	8

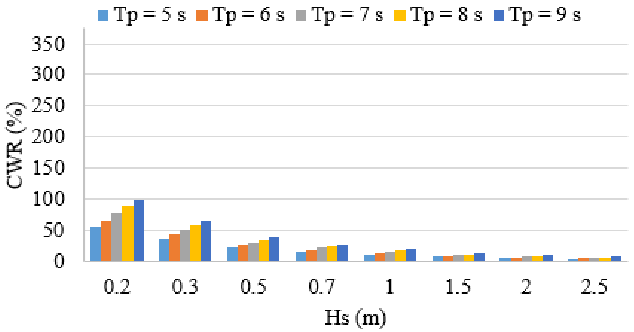
Hs/Tp	5	6	7	8	9
0.2	69	83	97	111	125
0.3	46	55	65	74	83
0.5	28	33	39	44	50
0.7	20	24	28	32	36
1	14	17	19	22	25
1.5	9	11	13	15	17
2	7	8	10	11	12
2.5	6	7	8	9	10

Hs/Tp	5	6	7	8	9
0.2	83	100	116	133	149
0.3	55	66	77	89	100
0.5	33	40	46	53	60
0.7	24	28	33	38	43
1	17	20	23	27	30
1.5	11	13	15	18	20
2	8	10	12	13	15
2.5	7	8	9	11	12

$i = 30$ $i = 30$ $i = 30$ $i = 30$







Hs/Tp	5	6	7	8	9
0.2	37	44	52	59	66
0.3	25	30	34	39	44
0.5	15	18	21	24	27
0.7	11	13	15	17	19
1	7	9	10	12	13
1.5	5	6	7	8	9
2	4	4	5	6	7
2.5	3	4	4	5	5

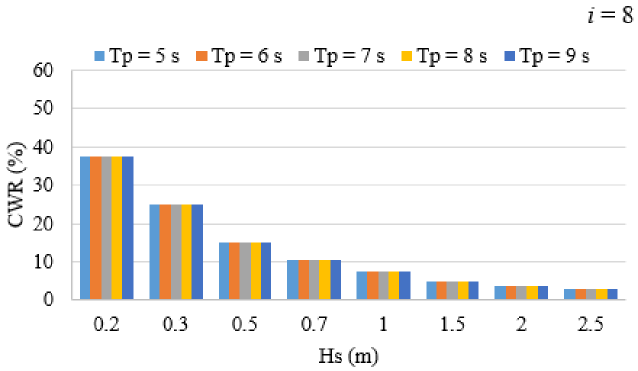
Hs/Tp	5	6	7	8	9
0.2	46	55	65	74	83
0.3	31	37	43	49	55
0.5	18	22	26	30	33
0.7	13	16	18	21	24
1	9	11	13	15	17
1.5	6	7	9	10	11
2	5	6	6	7	8
2.5	4	4	5	6	7

Hs/Tp	5	6	7	8	9
0.2	55	66	77	89	100
0.3	37	44	52	59	66
0.5	22	27	31	35	40
0.7	16	19	22	25	28
1	11	13	15	18	20
1.5	7	9	10	12	13
2	6	7	8	9	10
2.5	4	5	6	7	8

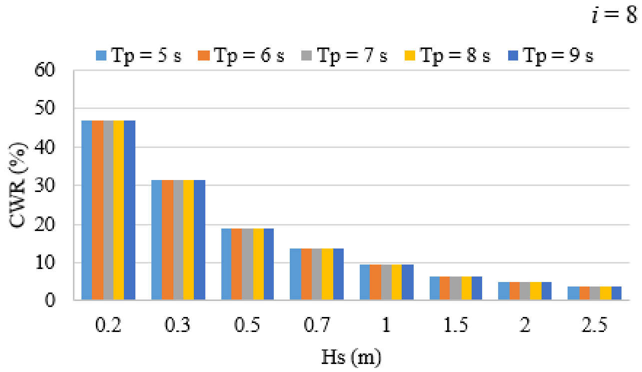
Table 7: Calculation for a feasible spacing condition ($d = 3m$).

Gear ratio	CF = 0.20	CF = 0.25	CF = 0.30

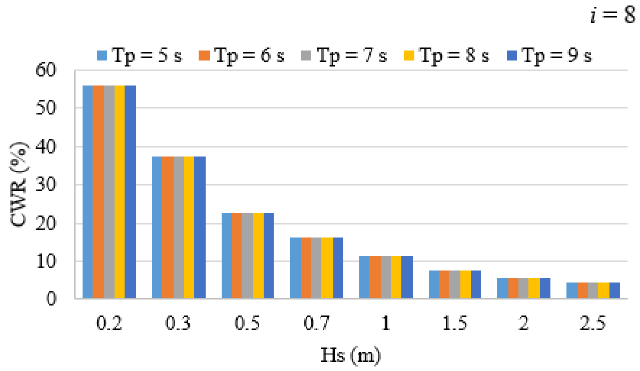
$i = 8$



Hs/Tp	5	6	7	8	9
0.2	37	37	37	37	37
0.3	25	25	25	25	25
0.5	15	15	15	15	15
0.7	11	11	11	11	11
1	7	7	7	7	7
1.5	5	5	5	5	5
2	4	4	4	4	4
2.5	3	3	3	3	3

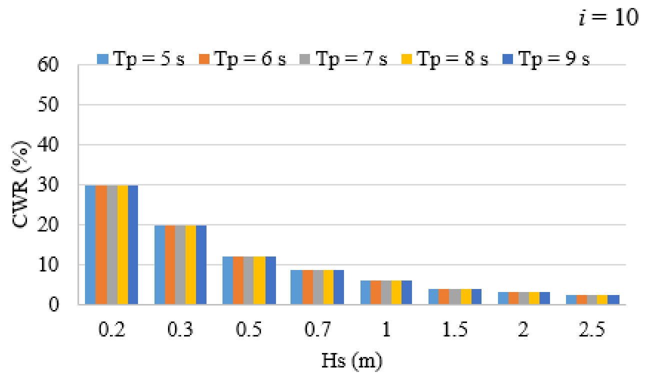


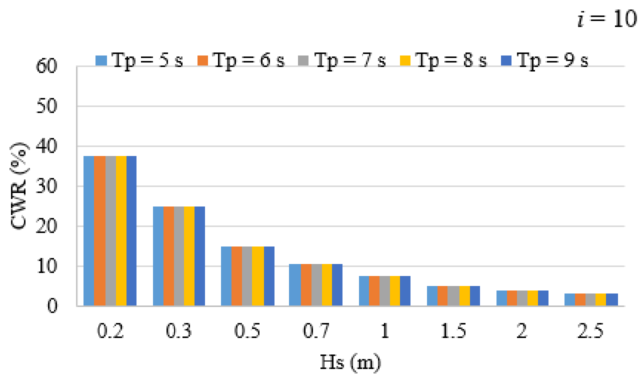
Hs/Tp	5	6	7	8	9
0.2	47	47	47	47	47
0.3	31	31	31	31	31
0.5	19	19	19	19	19
0.7	13	13	13	13	13
1	9	9	9	9	9
1.5	6	6	6	6	6
2	5	5	5	5	5
2.5	4	4	4	4	4

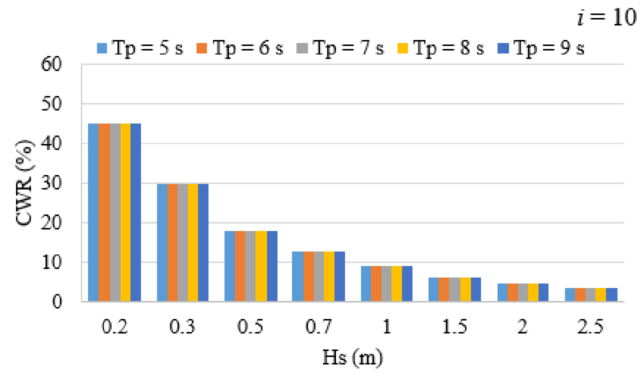


Hs/Tp	5	6	7	8	9
0.2	56	56	56	56	56
0.3	37	37	37	37	37
0.5	22	22	22	22	22
0.7	16	16	16	16	16
1	11	11	11	11	11
1.5	7	7	7	7	7
2	6	6	6	6	6
2.5	4	4	4	4	4

i = 10





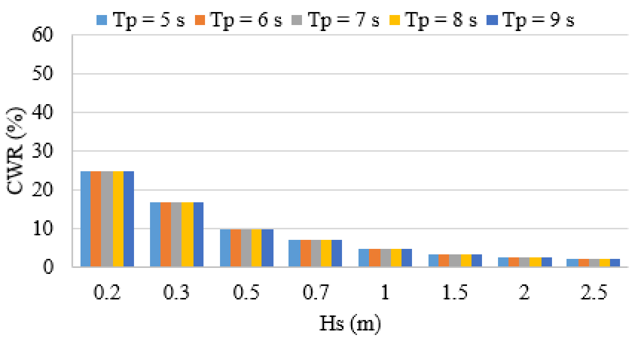


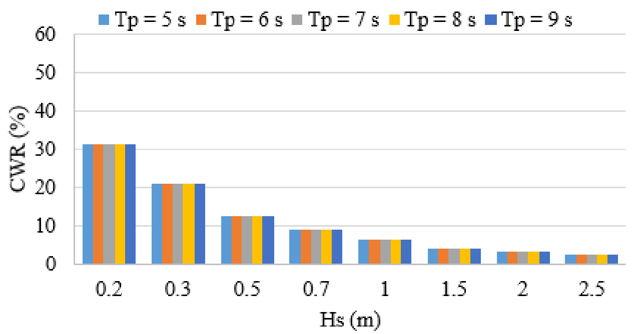
Hs/Tp	5	6	7	8	9
0.2	30	30	30	30	30
0.3	20	20	20	20	20
0.5	12	12	12	12	12
0.7	9	9	9	9	9
1	6	6	6	6	6
1.5	4	4	4	4	4
2	3	3	3	3	3
2.5	2	2	2	2	2

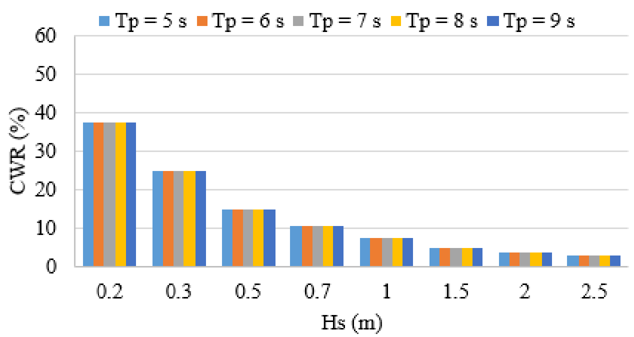
Hs/Tp	5	6	7	8	9
0.2	37	37	37	37	37
0.3	25	25	25	25	25
0.5	15	15	15	15	15
0.7	11	11	11	11	11
1	7	7	7	7	7
1.5	5	5	5	5	5
2	4	4	4	4	4
2.5	3	3	3	3	3

Hs/Tp	5	6	7	8	9
0.2	45	45	45	45	45
0.3	30	30	30	30	30
0.5	18	18	18	18	18
0.7	13	13	13	13	13
1	9	9	9	9	9
1.5	6	6	6	6	6
2	4	4	4	4	4
2.5	4	4	4	4	4

$i = 12$ $i = 12$ $i = 12$ $i = 12$





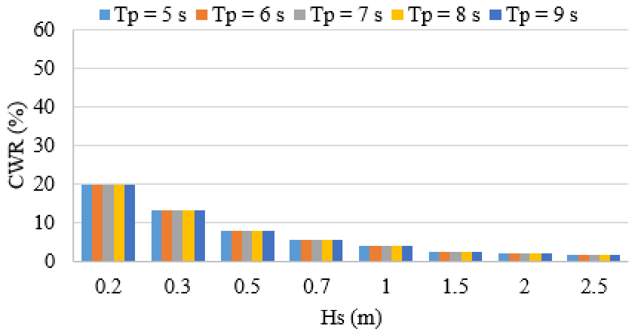


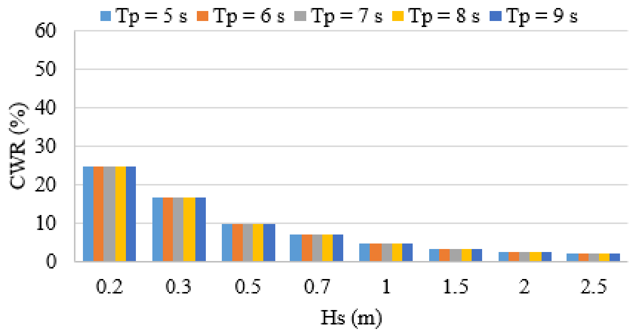
Hs/Tp	5	6	7	8	9
0.2	25	25	25	25	25
0.3	17	17	17	17	17
0.5	10	10	10	10	10
0.7	7	7	7	7	7
1	5	5	5	5	5
1.5	3	3	3	3	3
2	2	2	2	2	2
2.5	2	2	2	2	2

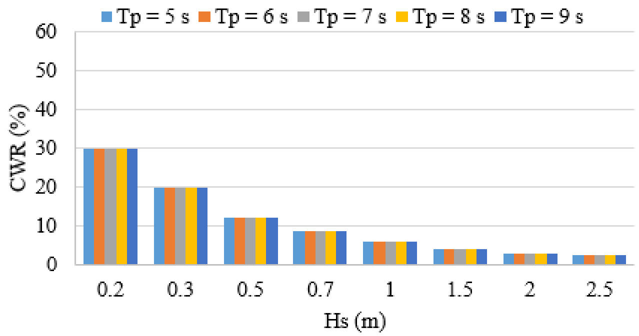
Hs/Tp	5	6	7	8	9
0.2	31	31	31	31	31
0.3	21	21	21	21	21
0.5	12	12	12	12	12
0.7	9	9	9	9	9
1	6	6	6	6	6
1.5	4	4	4	4	4
2	3	3	3	3	3
2.5	2	2	2	2	2

Hs/Tp	5	6	7	8	9
0.2	37	37	37	37	37
0.3	25	25	25	25	25
0.5	15	15	15	15	15
0.7	11	11	11	11	11
1	7	7	7	7	7
1.5	5	5	5	5	5
2	4	4	4	4	4
2.5	3	3	3	3	3

$i = 15$ $i = 15$ $i = 15$ $i = 15$







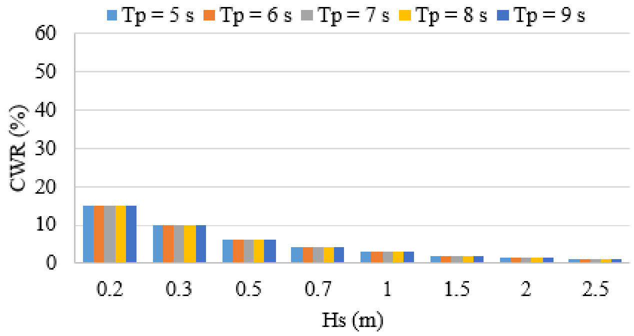
Hs/Tp	5	6	7	8	9
0.2	20	20	20	20	20
0.3	13	13	13	13	13
0.5	8	8	8	8	8
0.7	6	6	6	6	6
1	4	4	4	4	4
1.5	3	3	3	3	3
2	2	2	2	2	2
2.5	2	2	2	2	2

Hs/Tp	5	6	7	8	9
0.2	25	25	25	25	25
0.3	17	17	17	17	17
0.5	10	10	10	10	10
0.7	7	7	7	7	7
1	5	5	5	5	5
1.5	3	3	3	3	3
2	2	2	2	2	2
2.5	2	2	2	2	2

Hs/Tp	5	6	7	8	9
0.2	30	30	30	30	30
0.3	20	20	20	20	20
0.5	12	12	12	12	12
0.7	9	9	9	9	9
1	6	6	6	6	6
1.5	4	4	4	4	4
2	3	3	3	3	3
2.5	2	2	2	2	2

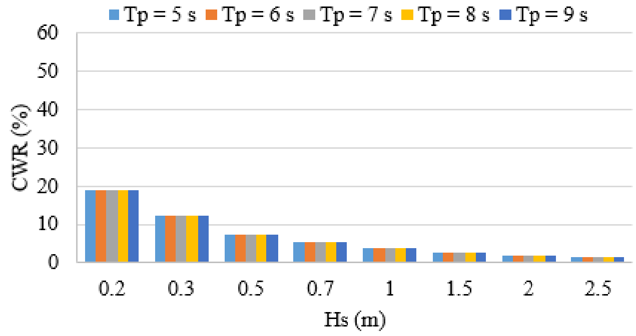
i = 20

i = 20



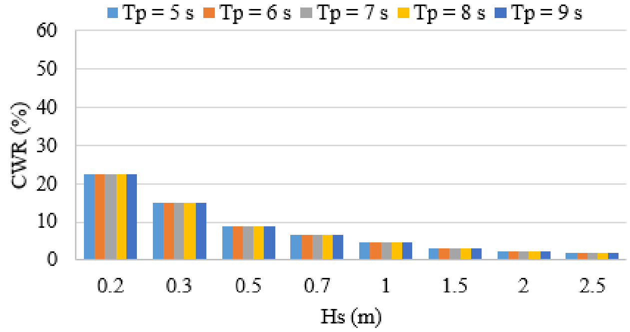
Hs/Tp	5	6	7	8	9
0.2	15	15	15	15	15
0.3	10	10	10	10	10
0.5	6	6	6	6	6
0.7	4	4	4	4	4
1	3	3	3	3	3
1.5	2	2	2	2	2
2	1	1	1	1	1
2.5	1	1	1	1	1

i = 20



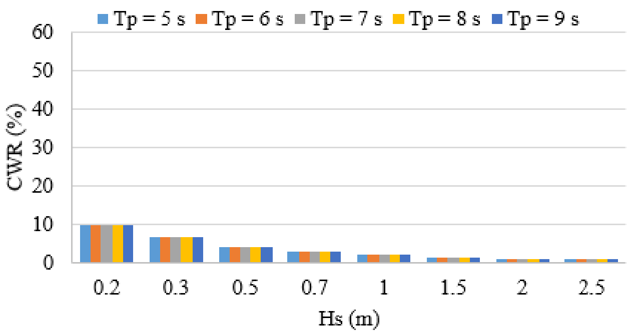
Hs/Tp	5	6	7	8	9
0.2	19	19	19	19	19
0.3	12	12	12	12	12
0.5	7	7	7	7	7
0.7	5	5	5	5	5
1	4	4	4	4	4
1.5	2	2	2	2	2
2	2	2	2	2	2
2.5	1	1	1	1	1

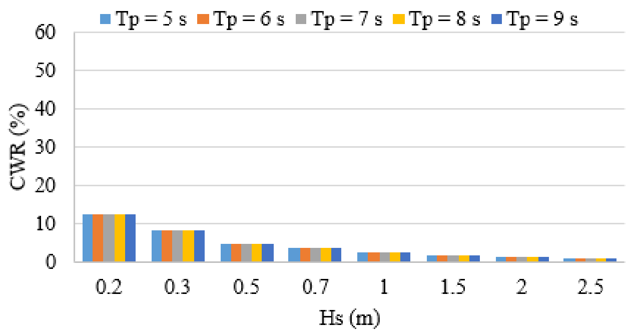
i = 20

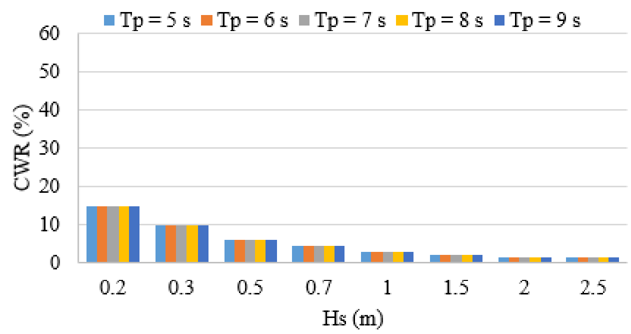


Hs/Tp	5	6	7	8	9
0.2	22	22	22	22	22
0.3	15	15	15	15	15
0.5	9	9	9	9	9
0.7	6	6	6	6	6
1	4	4	4	4	4
1.5	3	3	3	3	3
2	2	2	2	2	2
2.5	2	2	2	2	2

$i = 30$ $i = 30$ $i = 30$ $i = 30$







Hs/Tp	5	6	7	8	9
0.2	10	10	10	10	10
0.3	7	7	7	7	7
0.5	4	4	4	4	4
0.7	3	3	3	3	3
1	2	2	2	2	2
1.5	1	1	1	1	1
2	1	1	1	1	1
2.5	1	1	1	1	1

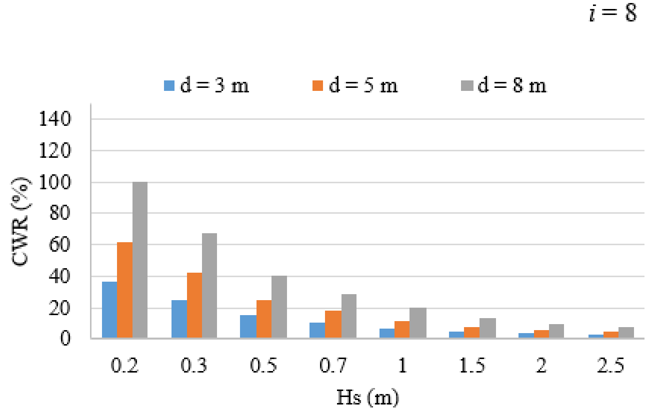
Hs/Tp	5	6	7	8	9
0.2	12	12	12	12	12
0.3	8	8	8	8	8
0.5	5	5	5	5	5
0.7	4	4	4	4	4
1	2	2	2	2	2
1.5	2	2	2	2	2
2	1	1	1	1	1
2.5	1	1	1	1	1

Hs/Tp	5	6	7	8	9
0.2	15	15	15	15	15
0.3	10	10	10	10	10
0.5	6	6	6	6	6
0.7	4	4	4	4	4
1	3	3	3	3	3
1.5	2	2	2	2	2
2	1	1	1	1	1
2.5	1	1	1	1	1

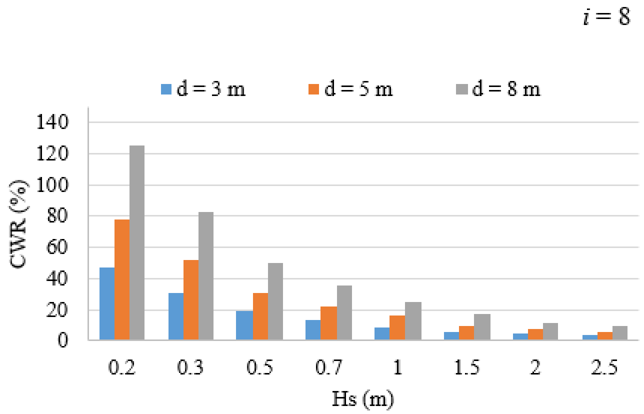
Table 8: Assessment of spacing variations (d =3, 5 and 8 m).

Gear ratio	CF = 0.20	CF = 0.25	CF = 0.30

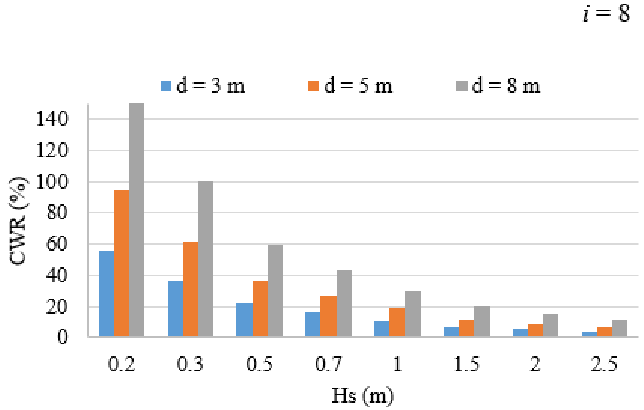
$i = 8$



Hs/d	3	5	8
0.2	37	62	100
0.3	25	42	67
0.5	15	25	40
0.7	11	18	29
1	7	12	20
1.5	5	8	13
2	4	6	10
2.5	3	5	8

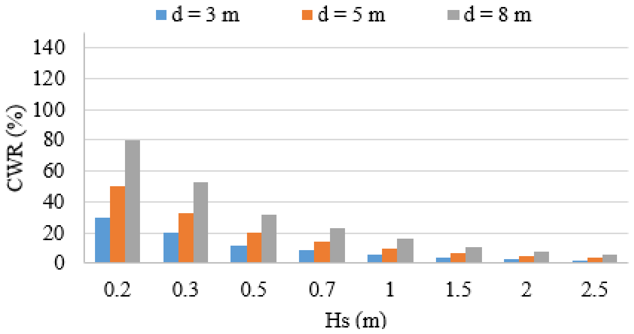


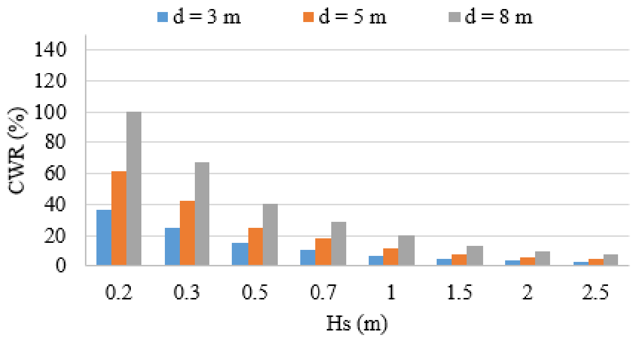
Hs/d	3	5	8
0.2	47	78	125
0.3	31	52	83
0.5	19	31	50
0.7	13	22	36
1	9	16	25
1.5	6	10	17
2	5	8	12
2.5	4	6	10

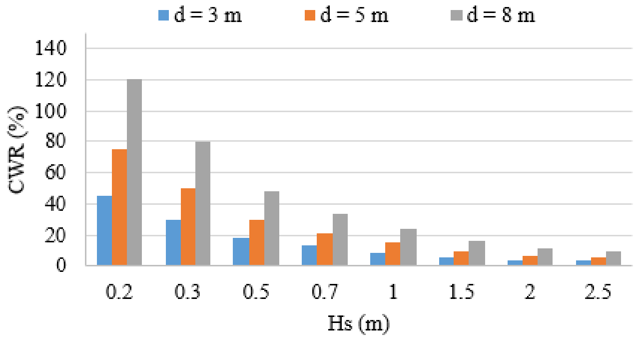


Hs/d	3	5	8
0.2	56	94	150
0.3	37	62	100
0.5	22	37	60
0.7	16	27	43
1	11	19	30
1.5	7	12	20
2	6	9	15
2.5	4	7	12

$i = 10$ $i = 10$ $i = 10$ $i = 10$





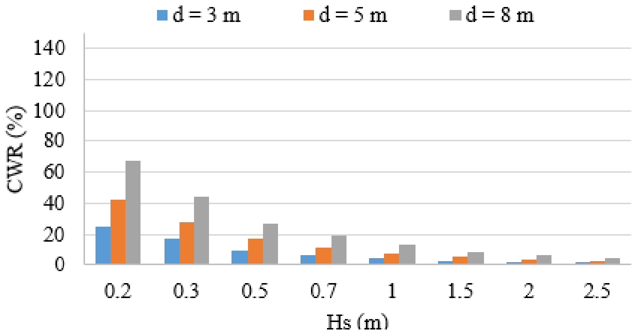


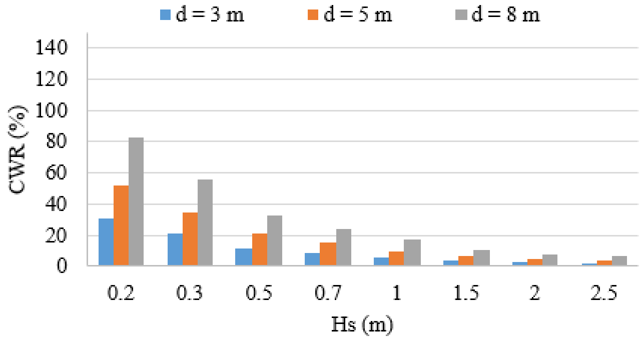
Hs/*d*	3	5	8
0.2	30	50	80
0.3	20	33	53
0.5	12	20	32
0.7	9	14	23
1	6	10	16
1.5	4	7	11
2	3	5	8
2.5	2	4	6

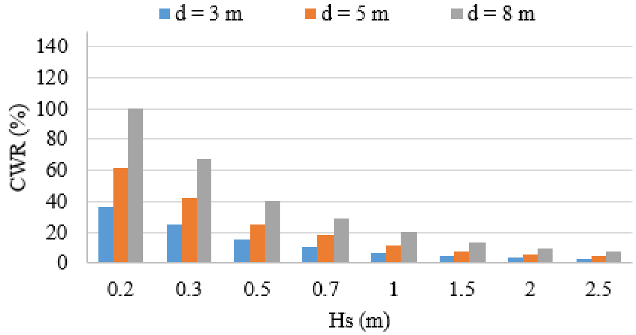
Hs/*d*	3	5	8
0.2	37	62	100
0.3	25	42	67
0.5	15	25	40
0.7	11	18	29
1	7	12	20
1.5	5	8	13
2	4	6	10
2.5	3	5	8

Hs/*d*	3	5	8
0.2	45	75	120
0.3	30	50	80
0.5	18	30	48
0.7	13	21	34
1	9	15	24
1.5	6	10	16
2	4	7	12
2.5	4	6	10

$i = 12$ $i = 12$ $i = 12$ $i = 12$





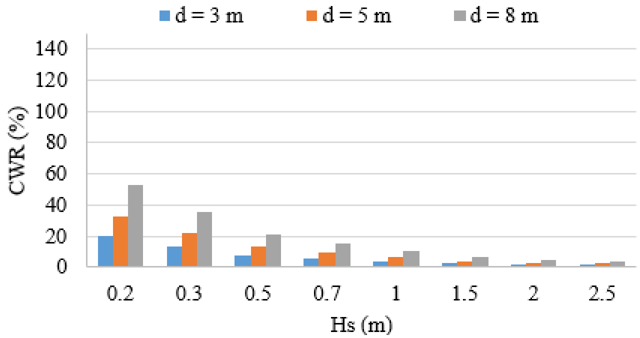


Hs/*d*	3	5	8
0.2	25	42	67
0.3	17	28	44
0.5	10	17	27
0.7	7	12	19
1	5	8	13
1.5	3	6	9
2	2	4	7
2.5	2	3	5

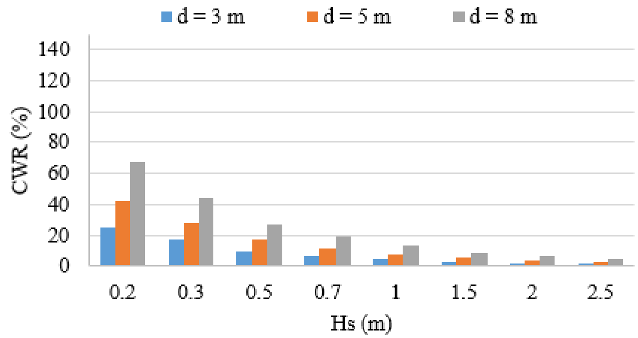
Hs/*d*	3	5	8
0.2	31	52	83
0.3	21	35	56
0.5	12	21	33
0.7	9	15	24
1	6	10	17
1.5	4	7	11
2	3	5	8
2.5	2	4	7

Hs/*d*	3	5	8
0.2	37	62	100
0.3	25	42	67
0.5	15	25	40
0.7	11	18	29
1	7	12	20
1.5	5	8	13
2	4	6	10
2.5	3	5	8

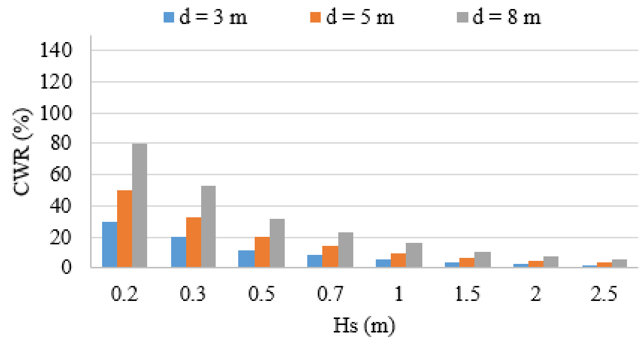
$i = 15$ $i = 15$ $i = 15$ $i = 15$



Hs/*d*	3	5	8
0.2	20	33	53
0.3	13	22	36
0.5	8	13	21
0.7	6	10	15
1	4	7	11
1.5	3	4	7
2	2	3	5
2.5	2	3	4

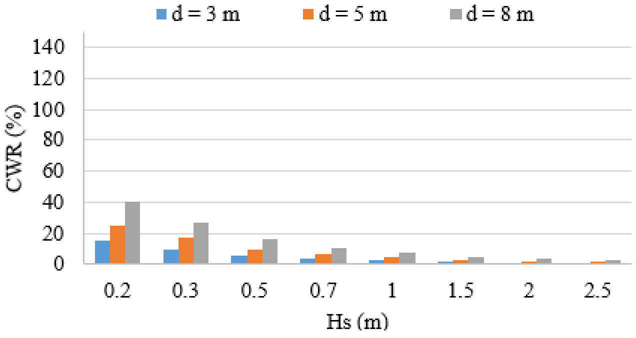


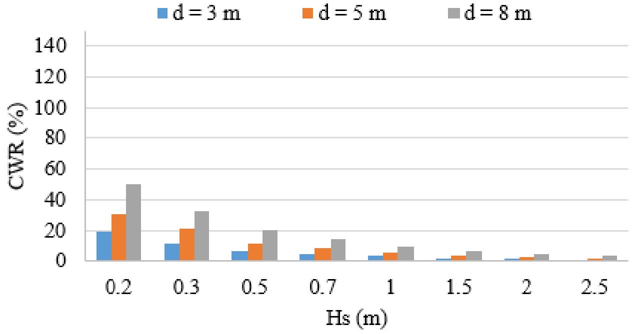
Hs/*d*	3	5	8
0.2	25	42	67
0.3	17	28	44
0.5	10	17	27
0.7	7	12	19
1	5	8	13
1.5	3	6	9
2	2	4	7
2.5	2	3	5

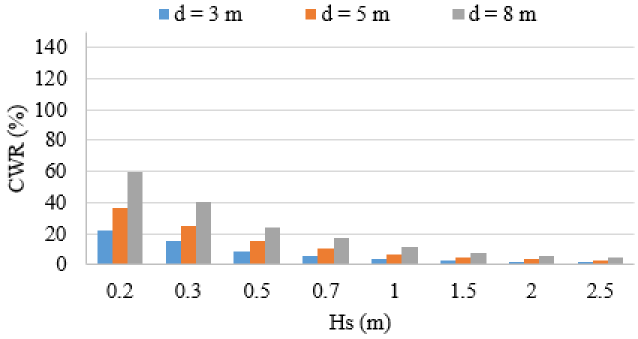


Hs/*d*	3	5	8
0.2	30	50	80
0.3	20	33	53
0.5	12	20	32
0.7	9	14	23
1	6	10	16
1.5	4	7	11
2	3	5	8
2.5	2	4	6

$i = 20$ $i = 20$ $i = 20$ $i = 20$







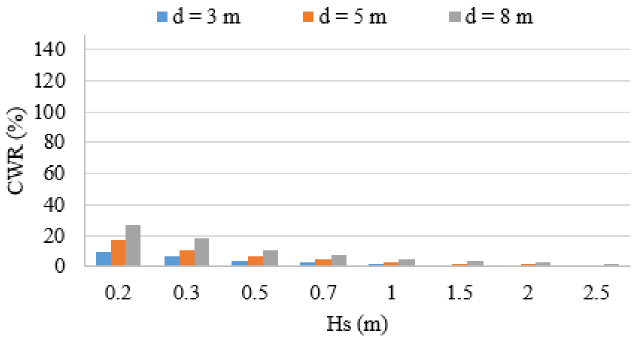
Hs/*d*	3	5	8
0.2	15	25	40
0.3	10	17	27
0.5	6	10	16
0.7	4	7	11
1	3	5	8
1.5	2	3	5
2	1	2	4
2.5	1	2	3

Hs/*d*	3	5	8
0.2	19	31	50
0.3	12	21	33
0.5	7	12	20
0.7	5	9	14
1	4	6	10
1.5	2	4	7
2	2	3	5
2.5	1	2	4

Hs/*d*	3	5	8
0.2	22	37	60
0.3	15	25	40
0.5	9	15	24
0.7	6	11	17
1	4	7	12
1.5	3	5	8
2	2	4	6
2.5	2	3	5

i = 30

i = 30



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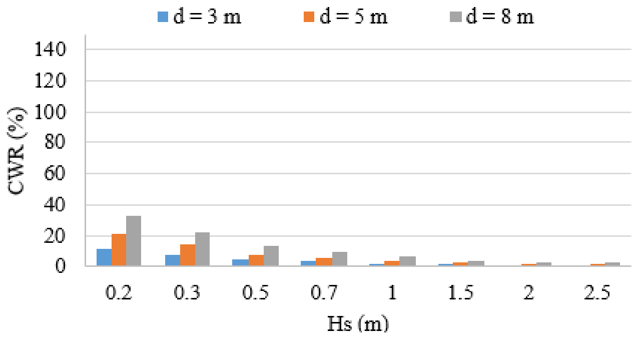

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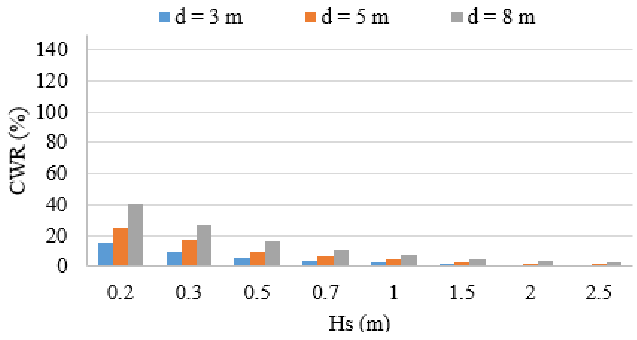

Hs/*d*	3	5	8
0.2	10	17	27
0.3	7	11	18
0.5	4	7	11
0.7	3	5	8
1	2	3	5
1.5	1	2	4
2	1	2	3
2.5	1	1	2

Hs/*d*	3	5	8
0.2	12	21	33
0.3	8	14	22
0.5	5	8	13
0.7	4	6	10
1	2	4	7
1.5	2	3	4
2	1	2	3
2.5	1	2	3

Hs/*d*	3	5	8
0.2	15	25	40
0.3	10	17	27
0.5	6	10	16
0.7	4	7	11
1	3	5	8
1.5	2	3	5
2	1	2	4
2.5	1	2	3

- Power production is maximized when the float spacing-to-wavelength ratio is 0.5.
- The ratio of 0.5 indicates the required inherent antiphase behavior, where one float is at a wave crest while the other is at a wave trough, to produce maximum power from the device.
- As the spacing between floats decreases, the average power also decreases for all wave periods.
- The CWR indicates that the device is utilizing approximately 53% of the available wave power under optimal conditions ($d = \lambda/2$) throughout the year, while it is around 18% under feasible conditions ($d = 3$, 5 and 8 m).
- Finding deployment locations that match the device′s resonant frequency, and have large wave heights, could aid in increasing device power performance. Additionally, this can also be achieved by increasing the wavefront of the proposed WEC.

5. ENVIRONMENTAL CRITERIA

Wave power contributes to sustainable economic growth by offering a clean, renewable energy source that can replace fossil fuels. It is important to note that although wave power has many economic benefits, there are also challenges associated with the implementation of wave power projects. The environment is a wide spectrum of things of which not all are of relevance to the in-situ application of the Wave Energy Converter. There are several environmental consequences to weigh before installing wave energy converters. Each type of WEC poses different environmental. The main difficulties involve the consequences to sea life and ship navigation. Additionally, the most important of which is the salinity of the surrounding water having its main influence on the corrosion rate of the used materials. The general classification of water salinity consists of fresh water (less than 0.05% saline), brackish water (0.05 to 3% saline), saline water (3 to 5% saline) and brine (over 5% saline). These water salinities have an effect in corrosion rate as well as water density where an increased salinity also increases the density.

A second important environmental factor to take into account is the presence of flora and fauna. Especially when parts are moving plant growth could become problematic and constricting. Adequate countermeasures would be required to counter this risk.

5.1. MARINE GROWTH

The structural analysis shall include the effects of marine growth that can impact the cross-sectional dimension and alter the hydrodynamic coefficients of structures that are submerged or in the splash zone. It is assumed the monopile used to support the structure will be periodically cleaned of all soft marine growth during maintenance. Therefore, in lieu of site-specific marine growth data, it is assumed that a one-year marine growth profile of 50 mm with a submerged density of 250 kg/m³ from the mudline to mean sea level shall be used for the structural assessment.

5.2. CORROSION ALLOWANCE

A corrosion allowance shall be applied to structural steel members in the splash zone. In lieu of more accurate data, a corrosion allowance of 5 mm shall be used. Corrosion protection would be required to meet the necessary design life. Protection can be obtained by using anodes to provide cathodic protection in the submerged zone, and specialized coating systems to provide protection in the splash zone. A painting system in the submerged zone may be used and should be considered in the next phase.

6. SEABED PROPERTIES AND FOUNDATION

For the concept development and analysis work completed in this phase, it is assumed the seabed will mainly comprise fairly smooth rock, as the high wave velocity will most likely wash all loose and light particles away. It is assumed a location will be available that will be reasonably flat to lay the monopile. For the stability and foundation analysis, the following properties shall be assumed [38]:

- Friction coefficient between concrete and seabed $\mu = 0.35$
- Seabed bearing pressure = 250 kPa
- Grout shear transfer strength = 100 kPa
- Geotechnical reduction factor on grouted connection = 0.5.

6.1. INFLUENCE OF SOIL CHARACTERISTICS ON FOUNDATION

This was primarily done because no actual information on the considered locations is available, but it also helps in making the calculations slightly easier. In reality, soil characteristics are rarely uniform and this has a certain influence on the bearing capacities of the different foundations. The following paragraphs will shortly address the influences different soil compositions have on the foundation for each of the soil materials.

6.1.1. Sand

There is a large variety in possible cone resistances in sand ranging from 2.7 up to well over 20 MPa. Practically 20 MPa is a realistic cut-off. This means that bearing capacities of piles and foundations in sand can range from 27% to 200% for precast concrete piles and shallow foundations as the cone resistance is proportional to the bearing capacity for those piles [38].

6.1.2. Clay

Clay, contrary to sand, has no real use in end bearing capacity and mostly plays a role in skin friction. For this reason, it is of influence to steel pipe piles and precast concrete piles. For both types of foundations, the influence is proportional with the cone resistance. With the possible cone resistance of clay ranging from 0.1 to 8 MPa. This means the bearing capacity range for clay is between 5% and 400% [38]. This is quite a significant range, but seeing as it applies per unit area it only plays a role if the thickness of the clay layer is significant.

6.1.3. Rock

Rock too exists with different capacities ranging from 0.55 (52%) to 1.40 (133%) MPa [39]. The determining factor for the rock′s strength is the formation of cracks. If cracks are present the bearing capacity of the rock reduces to the weight of the block that the anchor is placed in, as there is no possibility for load transfer between one side of the crack and the other. This is why the crack formation inside the rock needs to be mapped accurately before designing and installing the anchors and perhaps countermeasures need to be taken to either drill the holes deeper into another rock formation, reinforce the connection or use another foundation method.

6.2. FOUNDATION

The foundation consists of a reinforced concrete foundation base that will support monopile column. The foundation base will be grouted against the seabed in its in-place condition to provide the required lateral resistance.

The device is maintained and secured in the sea by a monopile foundation, which allow the device to be lifted above the water for maintenance and to survive harsh wave conditions parking safely at the top of the monopile. The device is put back in the sea only when the conditions are favorable. The tall column can be used to provide a working platform to house the nacelle, electrical compartment and supporting mast for housing the power cable.

A lifting mechanism will be installed to allow the structure to be lifted above the ocean water to access the device for maintenance. Figure 10 illustrates the structure moved along the column and above the waterline.

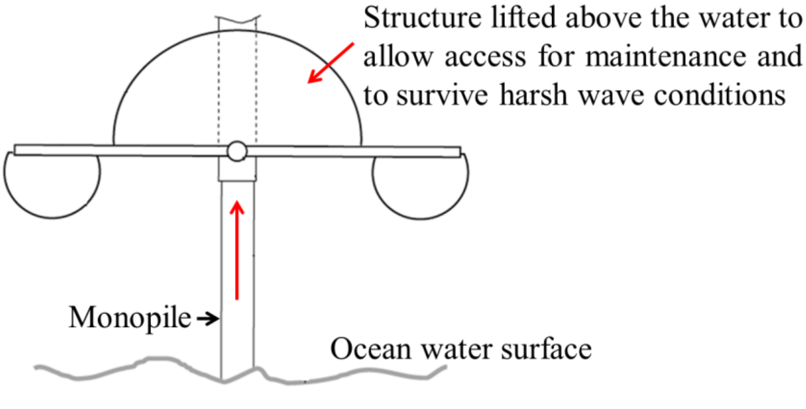

Figure 10: The device is shown parked above the waves.

7. POWER TRANSMISSION

The WEC is designed to use aerial cabling ashore, avoiding the need for expensive subsea cabling. A graphic of the aerial power cable run is shown in Figure 11. The power can be transmitted in direct current, or as alternating current from the electrical compartment to power grid. In smaller off-grid installations the aerial cable may be connected directly to the user.

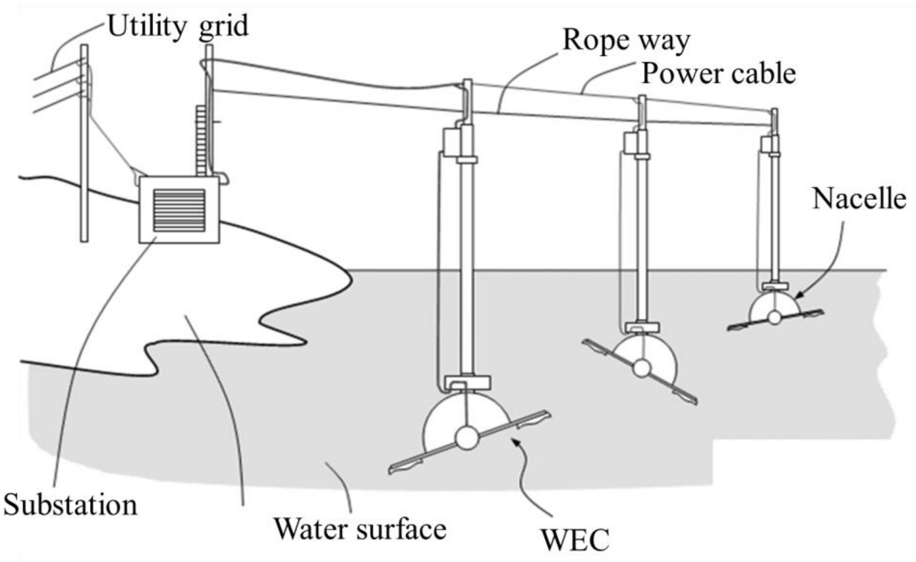

Figure 11: Schematic representation of several interconnected wave energy collectors.

In typical larger installations as shown in Figure 12, the aerial power line may connect a plurality of the proposed device to a substation, before being transmitted to the utility grid. Ropeways secured between the masts and land facilitates safe access to the installations for maintenance or trouble shooting works, even in rough sea condition.

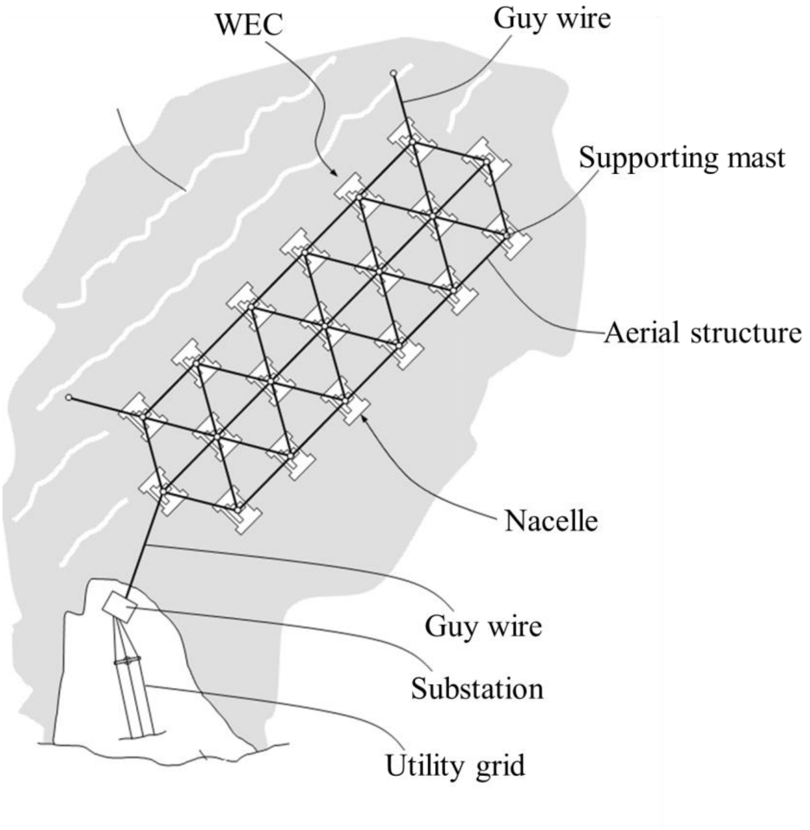

Figure 12: A plurality of interconnected wave energy devices within an energy farm.

8. WAVE BASIN LABORATORY EXPERIMENT

The physical testing of the WEC involved leakage, buoyancy and stability tests in the wave basin. The leakage must be conducted to ensure that there are no leaks in the terminators. This is a crucial test, as any leaks will compromise the terminator's ability to maintain buoyancy, which is essential for its overall functionality. The centre of gravity (COG) can be lowered by adding a ballast weight at the bottom to improve stability. This is an effective way to increase the stability.

8.1. STEPS FOR EXPERIMENTAL PLAN

8.1.1. Wave basin setup

The wave basin can be used to generate waves of various amplitudes and frequencies to simulate real-world conditions by installing a wave generator at one end of the tank. The generator should be programmable to create waves matching the average wave characteristics relevant to the study. This test will involve subjecting the WEC to various wave patterns and recording its oscillation to investigate fluid-structure interaction with the incoming waves.

8.1.2. Design and Fabrication

Developing a new device requires a thorough and iterative approach to design. The design process involved multiple optimizations that considered both feasibility and economics. The dimension of the terminators is also a key aspect of the design process along with mechanical PTO mechanism. These dimensions are carefully opted to ensure efficacy and functionality. In free-floating conditions, the terminator is expected to float by maintaining a designed draft. This is an important criterion of the design, as it ensured that the device would remain stable and not tumble. During the designing process, material, manufacturing, and economics are decisive factors that enabled the fabrication of an efficient and cost-effective device.

8.1.3. Power-Take-Off Design

The design of a rack and pinion-based mechanical generator is crucial for optimizing wave energy conversion. The generator is connected to an electrical compartment linked to a power cable to supply the electricity or to store the energy. The focus is on fine-tuning gear ratio to maximize energy capture efficiency. The chosen design must be reliable, easy to maintain, and efficient in converting wave energy.

8.1.4. Model Installation

For the model installation phase, the scaled WEC model should be securely mounted onto a monopile or a suitable foundation, ensuring that the model's draft, depth, and spacing are consistent with the specifications provided. These parameters should be maintained within the wave basin to accurately replicate the structure used in sea deployments, ensuring the experiment closely mimics nearshore anchoring conditions. Various sensors, including force sensors, torque meters, and displacement transducers, must be strategically placed at key points on the model to measure essential parameters such as wave force, buoyancy, generated torque, and motion dynamics. It is crucial to calibrate all sensors and the data acquisition system thoroughly to eliminate any baseline errors and ensure precise data collection before beginning the trials.

8.1.5. Testing procedure and data analysis

The testing procedure begins with initial test runs involving low-intensity wave simulations to assess the model's stability and its initial response to calm wave conditions. This step ensures that any adjustments needed for stability or measurement accuracy can be made early on. Following this, wave variability testing is conducted by gradually increasing the wave heights and periods to evaluate the model's adaptability to more challenging conditions. Multiple runs are performed at each wave setting to ensure data consistency and reliability. Throughout the testing phase, a real-time data acquisition system is employed to continuously collect data on the forces acting on the WEC, torque generated on the PTO system, motion dynamics, and power output.

For data analysis, the collected data is processed to calculate key performance indicators such as power absorption, capacity factor (the ratio of actual power output to its theoretical maximum), and capture width ratio, which reflects the WEC's efficiency in harnessing wave energy. A comparative analysis follows, where experimental findings are verified with theoretical calculations from numerical simulations to validate the experiment and refine future model improvements.

8.2. POTENTIAL CHALLENGES IN LABORATORY EXPERIMENTS

8.2.1. Scaling

When scaling real-world physics to a laboratory model, one major challenge is the discrepancy caused by non-linear scaling effects, such as differences in fluid dynamics and wave behavior, which can vary results. To address this, Froude scaling is commonly applied, ensuring similarity in wave generation and force measurements.

8.2.2. Wave Reflection and Basin Boundaries

One challenge in wave basin testing is the potential for waves to reflect off the basin walls, which can create standing waves or interference patterns that distort the WEC's performance. To address this, wave absorbers can be installed at the edges of the basin, or a damping mechanism can be implemented to reduce reflections. These measures help maintain clear and consistent wave patterns, ensuring more accurate and reliable results during testing.

8.2.3. Measurement Precision and Model Stability

Ensuring high accuracy in sensor calibration and data collection, especially for small wave forces, can be challenging. The solution involves regularly calibrating sensors and utilizing high-precision instruments to maintain data integrity. Additionally, it is important to ensure that electrical components are properly insulated and kept dry.

Another issue is maintaining the stability of the model under dynamic conditions, as instability can lead to skewed results. To overcome this, stable mounting and careful weight distribution must be incorporated into the model design. Environmental vibrations or noise from the wave generator can also introduce data noise, compromising sensor readings. Using data filtering techniques and shielding sensors from external disturbances can mitigate this problem.

8.2.4. Wave Generation Limits

Generating large or complex wave patterns might surpass the wave generator's capabilities. To handle this, experiments should be planned within the operational limits of the equipment, with trials conducted under consistent wave conditions to ensure reliable results.

8.2.5. Data Synchronization and Sensor Reliability

Synchronizing data from multiple sensors, such as those measuring force, displacement, and torque, in real-time is essential for accurate analysis. However, errors or delays in data capture can lead to incomplete or inconsistent results, compromising the integrity of the experiment. To mitigate this risk, a robust data acquisition system with built-in redundancy should be employed to ensure continuous data flow, even in the occurrence of sensor failure. Additionally, performing regular equipment checks and calibrations can help identify potential issues before they affect the reliability of the data.

This comprehensive plan for the wave basin experiment, along with detailed identification of potential difficulties, supports ensure the experiment is conducted with precision and realism, maximizing the reliability and validity of findings.

9. TESTING PLAN FOR SEA TRIAL

The aim of the sea trial is to assess the full-scale WEC in terms of its functionality, power output, and resilience within a real-world nearshore environment, ensuring the design meets performance expectations under real sea states.

9.1. STEPS FOR IMPLEMENTATION

9.1.1. Site Selection and Preparation

The first step involves selecting a site with wave characteristics that align with the study's goals. Additionally, an environmental impact assessment must be conducted to evaluate potential ecological effects and secure the necessary permits for deployment. Safety protocols are critical, and coordination with local authorities and marine experts is essential for smooth operations.

9.1.2. Deployment of the WEC

The WEC is transported to the trial site using suitable marine vessels, where it will be anchored securely using a monopile or a similar structure that can withstand marine forces. Instrumentation is then set up, including sensors to monitor wave force, torque on the PTO system, water depth, and power generation. A backup data recording system must also be installed to ensure that no critical data is lost during testing.

9.1.3. Running the Sea Trial

The trial begins under calm sea conditions to ensure baseline measurements, gradually progressing to testing in more intense wave conditions. Continuous data recording is crucial, covering a range of wave heights and periods to account for various sea states. Power generated is transmitted via an overhead system or a temporary cable setup to a nearby analysis station for monitoring.

9.1.4. Post-Trial Analysis

After the trial, the collected data is analysed to evaluate key performance metrics such as power output, capacity factor, capture width ratio, and overall mechanical performance. Additionally, the WEC's resilience is assessed by examining its response to extreme sea states and identifying any signs of wear or damage to the device. This analysis helps determine the long-term viability and robustness of the design in real-world conditions.

9.2. POTENTIAL DIFFICULTIES AND ISSUES IN SEA TRIALS

During the sea trial of a full-scale WEC, several challenges must be addressed to ensure smooth operations and reliable results. These challenges include site selection, weather variability, transportation, skilled workforce, operation costs, permissions and regulations, diver availability, lack of standardized operating procedures, and data recording.

9.2.1. Site Selection

Choosing the right location for sea trials ensures the project's success. Factors such as wave height, wave period, swell, water depth, current, and sea bed characteristics should be considered when selecting a location. The timing of sea trials is also important, as weather and environmental conditions can affect the device's performance.

9.2.2. Weather Variability

Unpredictable weather conditions can significantly disrupt testing schedules or even damage equipment. To mitigate this, trials should be planned during periods of stable weather forecasts, and robust anchoring systems must be implemented to withstand unexpected weather events.

9.2.3. Deployment Logistics

Transporting and installing the WEC in the ocean requires significant coordination and resources. This can be streamlined by employing professional marine contractors and ensuring well-organized logistics that include proper vessel selection, equipment, and personnel for the deployment process. A ship with a crane is required for the deployment. However, due to the lack of standardized operating procedures, an iterative process can be followed, which might be led to delays and complications.

9.2.4. High Costs and Resource Requirements

Conducting sea trials is an expensive undertaking due to the high costs of equipment, transportation, and personnel. To manage these costs, securing adequate funding is essential, and collaboration with academic institutions or governmental bodies for resource sharing can help reduce financial and logistical burdens. Additionally, compliance with government regulations and obtaining permission from port authorities can also lead to delays.

9.2.5. Data Transmission Issues

Collecting accurate data during sea trials is essential for evaluating the performance of the WEC. Offshore data transmission can face interruptions due to equipment failure or connectivity problems, potentially compromising the collection of critical performance data. This can be overcome by using a combination of wired and wireless transmission systems with redundant backups to ensure continuous data flow.

9.2.6. Environmental Impact

The sea trial could potentially affect local marine life and habitats, especially in ecologically sensitive areas. To minimize these impacts, the trial should be conducted in locations with low ecological sensitivity, and all activities should follow established guidelines to ensure the protection of marine environments.

9.2.7. Maintenance Access

Accessing the WEC for maintenance during the trial can be difficult, especially when sea conditions become rough. To address this, routine check-ups should be scheduled to monitor the WEC's performance, and emergency maintenance protocols should be in place with rapid-response teams on standby for unforeseen repairs.

10. APPLICATIONS

Wave energy conversion systems can be used in a variety of applications. These include:

- Electricity generation,
- Hydrogen production by electrolysis,
- Seawater desalination through reverse osmosis,
- Combined electricity/potable water production,
- Pumping/hydraulic power, and
- Navigation /environmental data acquisition.

11. CHALLENGES FOR WAVE ENERGY CONVERSION

Wave energy systems face a variety of challenges that must be addressed before they can be widely adopted. Among these challenges are potential disturbance or destruction of marine life, and concerns about coastal erosion. Additionally, these systems may interfere with commercial and sport fishing, as well as other recreational activities. The location of wave energy systems is also highly dependent on-site conditions, as they are sited in the marine environment. Other challenges include the maintenance requirements of such systems, power transmission and its associated capacity, and the variability of the energy resource. Furthermore, issues related to efficiency, economics, and the stage of development of the technology must also be considered. These factors collectively pose significant hurdles that need to be overcome for the successful deployment of wave energy systems.

The proposed monopile-mounted WEC system can be utilized to address and overcome such challenges associated with wave energy systems.

- *Disturbance or destruction of marine life*: Installation and operation of WECs can disturb habitats and ecosystems, potentially harming marine biodiversity. However, the proposed WEC′s minimal underwater footprint and lack of complex underwater components contribute to reduce habitat disruption. Additionally, careful site selection, away from sensitive ecosystems, can further mitigate ecological disturbances.
- *Coastal erosion*: WEC installations may alter natural sediment transport, potentially increasing coastal erosion. However, the monopile foundation of the proposed system causes minimal alteration to natural water flow and sediment movement, helping to reduce the impact on coastal dynamics.

- *Interference with commercial and sport fishing*: WECs can obstruct fishing activities, potentially affecting livelihoods and recreational interests. However, the compact design of proposed system reduces spatial interference, allowing fishing vessels to navigate around the system easily. Additionally, strategic placement outside major fishing routes minimizes disruption to such activities.
- *Interference with other recreational activities*: WECs can obstruct boating, surfing, and other nearshore activities. However, placing the system away from high-traffic recreational zones reduces the likelihood of conflicts. Deploying the system in less frequented areas or integrating it with existing infrastructure, such as breakwaters, further minimizes interference with these activities.
- *Location-dependent*: Wave energy potential varies significantly by location, limiting widespread deployment. However, real-time monitoring and adaptive control can optimize performance across different wave conditions.
- *Sited in marine environment*: Marine conditions pose challenges such as corrosion, biofouling, and extreme weather exposure. To address these, materials with high corrosion resistance and anti-fouling coatings are used to extend operational lifespan and reduce maintenance needs. Additionally, the system′s ability to park above waves during extreme weather helps reduce the risk of damage.
- *Maintenance requirements*: Marine environments increase maintenance frequency and costs due to wear, corrosion, and biofouling. Proximity to shore facilitates easier and faster access for maintenance. Additionally, modular design of the proposed system allows for specific components to be repaired or replaced without dismantling the entire system.

- *Power transmission*: Transmitting power from marine installations to shore can be expensive and prone to losses. The use of overhead power transmission lines significantly reduces costs compared to submarine cables, and their proximity to shore minimizes transmission distance, improving efficiency.
- *Efficiency*: Converting wave energy into usable power efficiently is a technical challenge. The proposed system′s design captures energy from a significant section of the wavefront, thereby improving the capture width and overall efficiency.
- *Economics*: High capital costs and long payback periods can hinder commercial adoption. The proposed system is cost-effective due to simplified installation using monopile foundations, elimination of expensive underwater cables, and low operational and maintenance costs due to its proximity to shore.

By addressing these challenges through innovative design and features, the proposed monopile-mounted WEC system positions itself as a practical, cost-effective, and environmentally responsible solution for nearshore wave energy harvesting. Its adaptability, combined with a focus on minimizing environmental and operational drawbacks, makes it a suitable alternative for implementation.

12. SUMMARY

This report aims the feasibility study of a nearshore wave energy converter for installation near the coast in shallow water to harness the wave power. The study involved a comprehensive literature review to determine if a similar method or device was already available in the open literature and summaries the relative merits among the wave energy converter systems.

The technical feasibility was assessed using numerical calculations for pitch response. It can be concluded that it is possible to deploy a device capable of extracting a certain amount of energy from the pitch response of the wave. The calculations in section 4 show that for a variety of boundary conditions a working solution can be designed that suffices for that scenario.

A comprehensive description is also provided to addresses the essential components for planning and conducting both laboratory and sea trials. This include identifying potential challenges and outlining practical solutions to ensure successful execution and reliable results throughout the testing process.

There are several key outcomes as listed below:

- The proposed wave energy system is designed mainly for nearshore deployment, particularly in shallow waters ranging from as low as 1 to 10 m depth.
- Concept is most appropriate for low energy wave intensity (5-10 kW/m).
- The device has been proposed to operate in shallow water depths of 1-10 meters.

- ❖ It utilizes a monopile foundation, which is cost-effective, easy to maintenance, and less invasive to construct.
- ❖ Energy is transmitted using overhead power lines, instead of costly submarine cables (cost effectively).
- ❖ The PTO uses wind power components that are widely available and less expensive compared to systems based on linear generators or hydraulic systems.
- ❖ The nearshore location of the system results in lower installation and operational costs.
- ❖ Able to survive harsh wave conditions by moving out of the ocean and parking safely at the top of the monopile.
- ❖ The numerical results show that the wave period (T) and the distance between the floaters (d) significantly influence the WEC's power absorption.
- ❖ For longer wave periods, the system absorbs more power but becomes less efficient at higher wave heights.
- ❖ The optimal spacing between the two floaters should be half of the wavelength or less, based on the calculated optimal distance of $\lambda/2$. This ensures that the device can harness wave energy effectively.
- ❖ The numerical calculations highlight that the nearshore WEC performs best under lower-energy, nearshore conditions, with optimal power absorption achieved at specific wave heights and periods.

Recommendations and future work

- ❖ Experimental investigation for a single unit can be performed in a lab-scale model before going into the prototype.
- ❖ To assess electrical power, analyses and experiments including PTO damping should be conducted.

- Cost analysis needs to be conducted to evaluate the techno-economic viability of the proposed concept.
- Environmentally suitable sites and their development potential (in terms of energy cost and installed capacity) should be cataloged before the deployment of WEC.

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