TECHNICAL BRIEF ON NEAR SHORE MONOPILE MOUNTED WAVE ENERGY COLLECTOR

INTRODUCTION

The proposed wave energy system is designed mainly for installation near the coast in shallow water ranging from as low as 1 to 10 meters. The concept is most appropriate for use in waves of low intensity, as is the case around the coast of India which is in the range of about 5-10 kW/m. The proposed system can be used as a standalone device or as a plurality of interconnected devices for high energy output. The system may be implemented for use in deeper water.

MAIN FEATURES AND ADVANTAGES

The main features of the proposed concept are as follows:

- It is a system based on mature technologies and technical knowhow. It can be easily manufactured, implemented, and operated at low cost.
- It is a floating type device with a low draught ideal for shallow water near the coast. The device can operate in depth of few meters only.
- The harnessed energy is cost effectively transmitted to the power network by the use of overhead power lines, instead of costly submarine cables.
- It has comparable advantage to shoreline wave energy devices, but without the need of large infrastructures on the shore.
- The device is maintained and secured in the sea by a monopile foundation, which is a less invasive construction. This is also cost effective and most reliable, compared to mooring systems generally use to secure floating type devices.
- The device is able to survive harsh wave conditions by moving out of the ocean and parking safely at the top of the monopile. The device is put back in the sea only when the conditions are favorable. Such a process would be normally automated not requiring human intervention.
- The installation in its common configuration is easily and safely accessible to maintenance teams without the need of wartercrafts. Ropeways are provided

from land to the plurality of devices within an energy farm. Access is not conditional to the state of the ocean.

- There are no underwater equipments. This greatly contributes to reduction of installation and operation cost.
- The power-take-off system (PTO) comprises of equipment used in wind power systems, which are widely available off-the shelf. PTO based on linear generators or hydraulic systems are comparatively very costly.
- The device makes use of a water ballast to provide necessary counterweight for the PTO, rather than ballasts made of metal or concrete. This contributes to reduction of cost.
- The hydrodynamic system of the proposed device is able to collect a significant amount of energy from a larger section of the wavefront. This feature enables higher power output in waves of lesser intensity.
- The moving part of the device has a low mechanical inertia, and this improves the power extraction ability in waves of shorter periods.
- The device has a low environmental impact because of a low footprint and a minimum wetted area given that most of the system is above the waterline.
- The device is not harmful to aquatic life due to absence of fast moving submerged parts.

A GENERAL DESCRIPTION OF THE PROPOSED DEVICE

The wave energy collector or device shown in FIG. **1** comprises of a nacelle **21** mounted on a mast **22**. The mast **22** is preferably a single monopile secured to the seabed **25** which extends above the water surface **23**. The nacelle **21** is free to move up and down the mast **22** during operation. For that purpose, the nacelle **21** comprises of a trolley **26** with rolling contacts on guide rails **27** which are secured to the mast **22**. The nacelle **21** is able to adapt to the tides varying heights by moving along the mast **22**.

The nacelle **21** is completely buoyant on the surface of the ocean **23**. It comprises of a rigid platform **28** equipped with a pair of buoyant components or terminators **31** secured firmly at the extreme front and rear. The rigid platform **28** is mounted about a pivot **29** which is firmly secured to the trolley **26**. Articulating movements of the platform **28** about the pivot **29** during interaction with incoming waves operate the power-take-off within the enclosure **32**. The terminators **31** are aligned with the incoming wavefronts and the distance between the terminators **31** does not exceed ½ the distance between succeeding wavefronts. The terminators **31** together with the platform **28** are constructed as light as possible in order to limit rotational inertia of the articulating mechanisms, hence maximising power extraction capacity of the system. The terminators **31** are of significant length in order to collect as much energy from the wavefronts and surges.

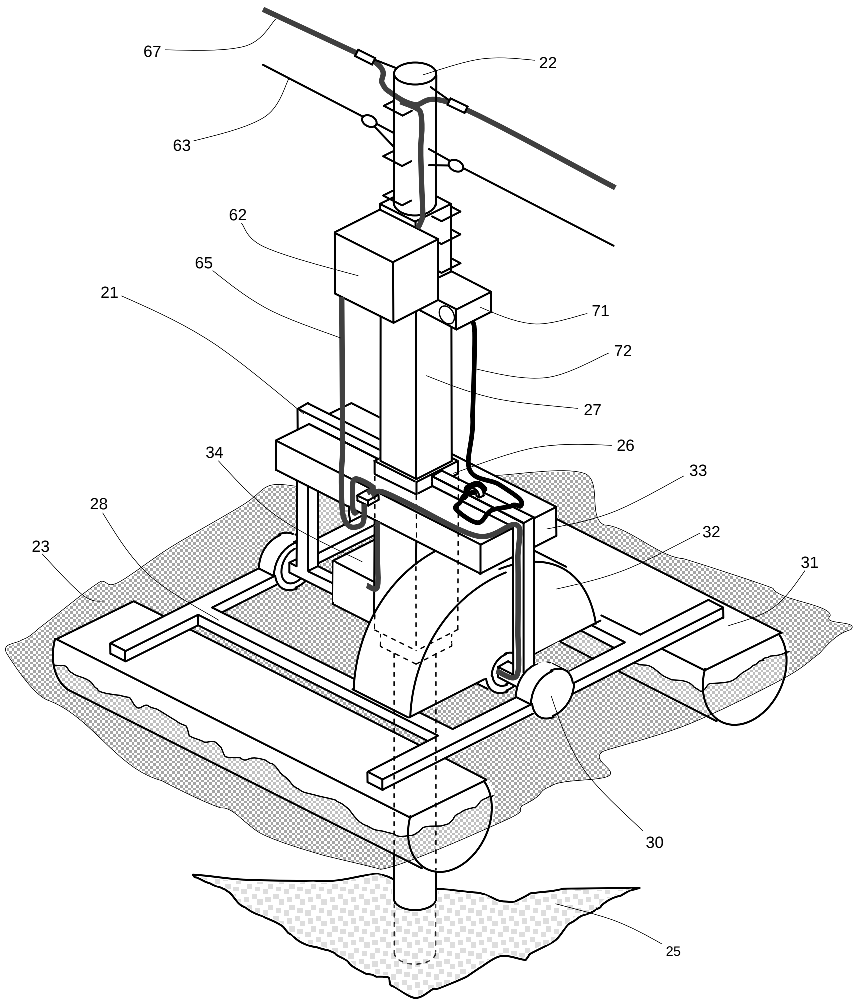


Figure 1. A pile mounted wave energy device is shown in a standalone configuration.

The forces which operate the PTO are provided by the buoyant forces acting on the terminators **31**, the weight of the nacelle **21** together with the weight of a water ballast **33**, and the resistive forces of the mast **22**. The ballast **33** is secured to the trolley **26**. The power extraction capacity of the PTO may be adjusted according to the volume of water in the ballast **33**. A means to fill and empty the ballast **33** is provided by a pump system **34**. Sudden excess energy from rogue waves is diverted safely and smoothly away from the PTO in displacing the nacelle **21** upward along the mast **22**. The excess wave energy gets stored as potential energy as the nacelle **21** rises up the mast **22**, and then safely discharged or absorbed by the PTO as the nacelle **21** returns down the mast **22** under the force of gravity. Wave energy is extracted by the PTO only due the pitching movements of the platform **28** about the pivot **29**, and not due the moderate heaving movement of the nacelle **21** that may exist.

The PTO preferably comprises of a single stage direct drive gear mechanism. The space above the platform **28** generously allows the installation of a large diameter rack and pinion so as to have a high gear ratio. This enables conversion of the high torque-slow movement of the platform **28** into higher speed-low torque rotation compatible with the generator. The pinion rotates a generator to produce electrical energy. Chain, belt or rope transmissions are other suitable alternatives to gearbox in spite of lower efficiency, as they may offer a better compromise between cost and efficiency. As the generator rotates forward and backward it produces a fluctuating AC supply, which is rectified before being fed to a DC/AC converter. The supply from the DC/AC converter is then transmitted to the grid by the power lines **67**. The rectifier and DC/AC converter are located in the electrical compartment **62**. The power system may comprise of temporary energy storage system, such as capacitors and batteries. A trailing cable **65** interconnects the equipments in the enclosure **32** and those in the electrical compartment **62**.

In smaller off-grid installations the aerial cable **67** may be connected directly to the user. In typical larger installations as shown in FIG. **2** the aerial power line **67** may connect a plurality of the proposed device **20** to a substation **68**, before being transmitted to the utility grid **69**. Ropeways **63** secured between the masts **22** and land facilitates safe access to the installations for maintenance or trouble shooting works, even in rough sea condition.

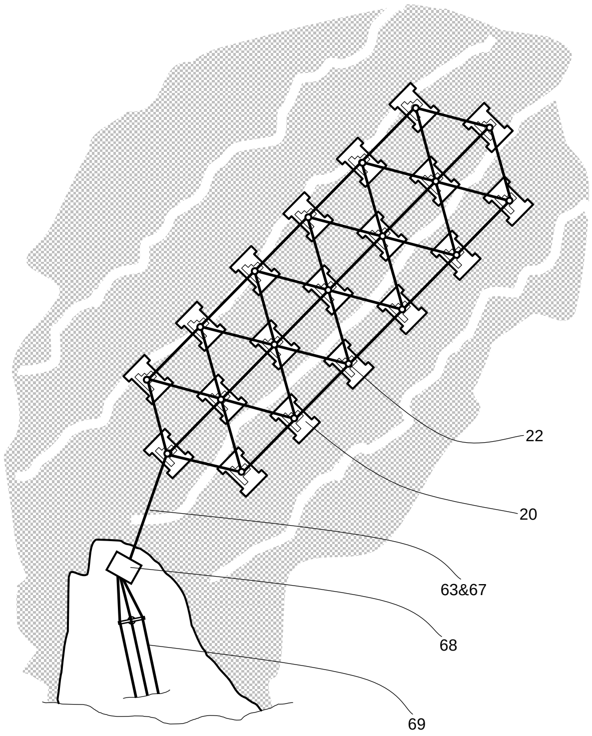


Figure 2. A plurality of interconnected wave energy devices is shown within an energy farm.

An electrical hoist **71** enables to raise or lower the nacelle **21** as required. The nacelle **21** is shown in a parked position at the top of the mast **22**, in FIG **3.** The nacelle **21** is raised when the waves are too intense for safe operation or during maintenance and repairs. The power to operate the electric hoist **71** can be tapped from the aerial power cable **67** which are generally permanently energised or from an auxiliary power supply such as a battery.

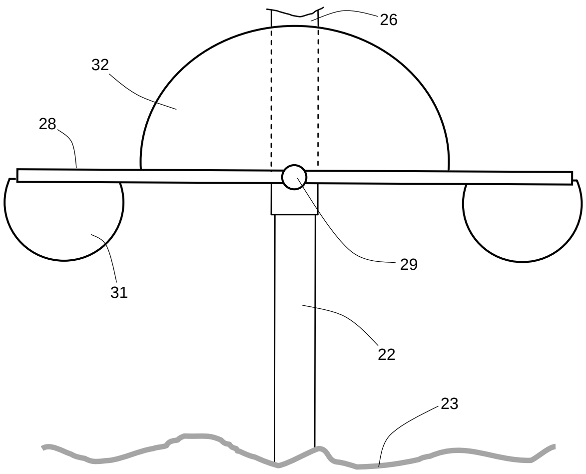


Figure 3. The nacelle is shown parked above the waves.

The propose wave energy device is most suitable for installation near the coast given the lower erection cost of pile foundations, the use of convention aerial power cables **67**, and easy access to the installation for maintenance. Close to the shore where the waves are not intense, the device may be designed to generate power in the range of 5 to 20 KW. At locations where the waves are more intense a single device may generate energy in the range of hundred kilowatts. Energy farms comprising of many interconnected devices of small capacity would have a huge combined power capacity of several hundreds kilowatts or megawatt. The mast **22** may also conveniently accommodate wind turbines or solar panels.

KINETIC DIAGRAM OF THE PTO AND OPERATION

Wave energy is extracted as the platform **28** pitch from side to side about the pivot **29**, as describe in FIG. **4**, under the buoyant forces acting on the two terminators **31**, as the wave crest travels from one to another. Wave surges would also reinforce the pitching movement of the platform **28** increasing the energy harnessed. A curve rack **45** of large equivalent gear diameter sitting on the platform is made to drive a pinion **43** so as to provide a high gear ratio which matches the operational requirement of the generator **44**. The generator **44** rotates back and forth as the platform **28** pivots from side to side.

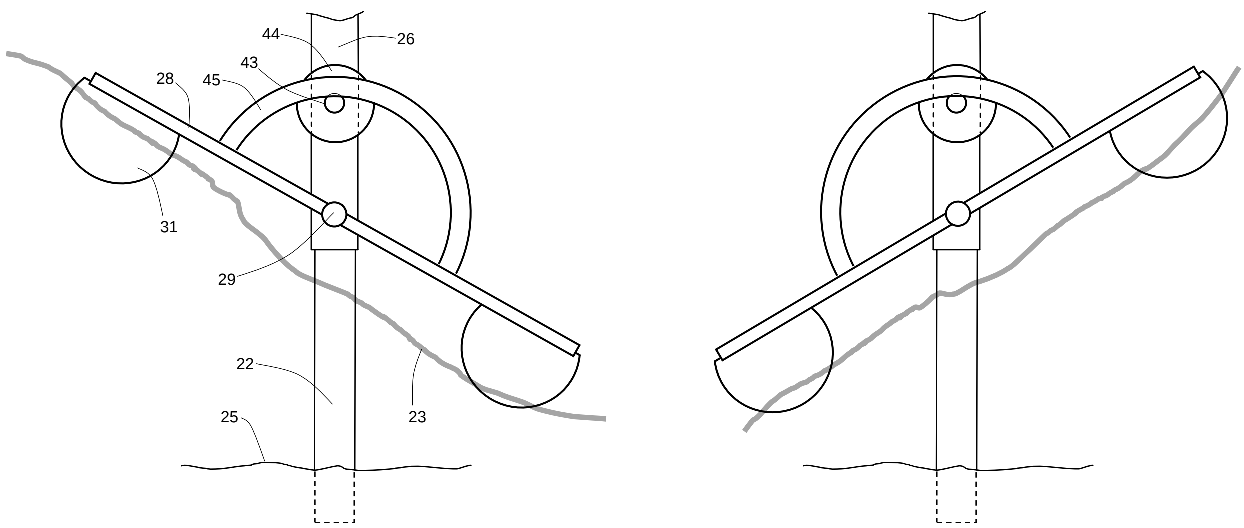
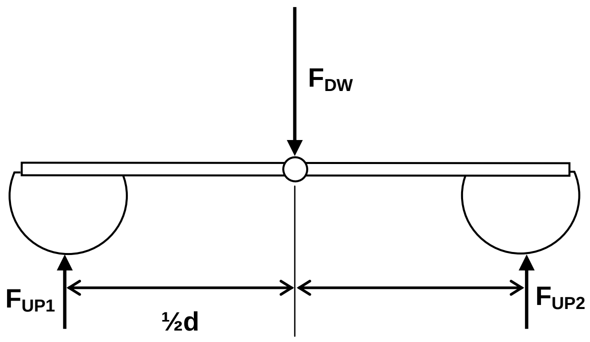


Figure 4. The pitching movements of the platform due interaction with the wave operating the PTO.

The forces necessary to generate the torque on the generator is shown in FIG. **5**. It is provided by the resultant buoyant force $\mathbf{F_{UP1}}$ and $\mathbf{F_{UP2}}$ due to both terminals **31** and the downward force $\mathbf{F_{DW}}$. $\mathbf{F_{DW}}$ is the combined weight of the whole nacelle **21** including the water in the ballast **33**.



$F_{DW} = F_{UP1} + F_{UP2}$ (In static condition)

$T_{PTO} = (F_{UP1} - F_{UP2}) \times \frac{1}{2}d \times \cos\theta_p$

$T_{PTO}\,MAX = F_{DW}$

$T_{GEN} = T_{PTO} / i$

$P_{GEN} = T_{PTO} \times \frac{d\theta_p}{dt} \times Eff.$

where,

T_{PTO} is the torque operating the PTO

T_{GEN} is the torque on the generator

θ_p is the pitching angle of the platform

i is the gear ratio

EFF. is efficiency of generator and gear mechanism

d $<$ ½ the distance between succeeding wavefronts

Figure 5. The main forces operating the PTO.

ELECTRICAL SCHEMATIC OF THE PTO

A schematic of the electrical system within the enclosure **32** and **62** is shown in FIG. **6**. A low rpm PMG generator converts the mechanical energy into electricity, as this allows the gearbox to have a lower gear ratio. The back and forth rotation of the generator produces non-sinusoidal alternating power supply, which is first rectified before further conditioning in a DC/AC convertor before transmission to the power grid. The generator and the invertor are equipments used in wind power systems.

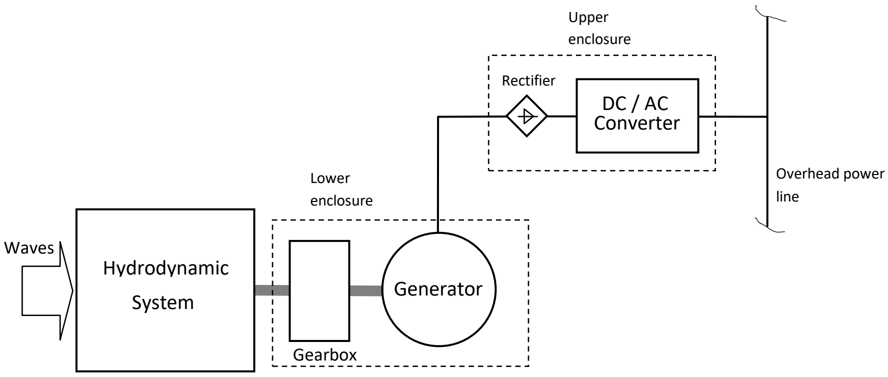


Figure 6. Electrical schematic of the PTO with the main components.

A single standalone device being used off the grid would produce a pulsating power supply and would require power storage system such as batteries for a smooth supply. In the case of a plurality of well distributed interconnected devices the power fluctuation is minimised. In grid connected installation power storage is not required.

PARAMETERS GUIDING THE DESIGN OF THE WAVE DEVICE

- The dimension of the terminal **31** is determined based on the max. upward force $\mathbf{F_{UP}}$, needed to enable pitching of the platform **28**. $\mathbf{F_{UP}}$ may exceed $\mathbf{F_{DW}}$, given that a single terminal **31** may have to provide all the forces necessary to maintain the nacelle **21** afloat. The size of the terminal **31** is then calculated based on the Law of Flotation. The length of the terminals **31** may range between 5 to 10 meters in order to produce the desired amount of torque for operation of the PTO.
- The torque acting about the pivot **29** is approximately the product of the resultant force $\mathbf{F_{UP}}$ of both terminals **31** and **d**, where **d** is ½ the distance between the terminal **31**. The optimum distance between the two terminals **31** is ½ wavelength of the wave, or less.
- The mass of the platform **28** together with the terminals **31** is the source of certain amount of inertia during dynamic interaction of the device with the waves. It can be assume to be about 5-10% the mass calculating for $\mathbf{F_{DW}}$.
- Torque on the PTO is limited to $\mathbf{F_{DW}}$ **X ½ d**, given that the pivot **29** is free to move about the vertical.

OBJECTIVES OF THE NUMERICAL STUDY

The numerical study will provide useful information about the hydrodynamic efficiency of the system for waves of varying intensity and periods, for various parameters of $\mathbf{F_{DW}}$ and corresponding size of terminals **31**. The intensity and periods of the waves should include those most common in India and should take into consideration the seasonal variations.

Knowing the power extraction capacity per unit length of the terminals **31** for the most optimum variant, a reliable estimate of the general dimensions of the terminals **31** for a device of desired power capacity may be calculated, considering mechanical and electrical loss in the PTO.

This would enable the construction of a prototype having an output in the range of 5-10 KW or even more, operating a few meters off the beach in India. We believe that this is an achievable objective, and is our set goal. A further step would be the implementation of a mini energy farm for demonstration purposes.