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A STUDY ON WAVE ENERGY CONVERTER TECHNOLOGIES

Dr. Pavankumar Singh*

*Faculty of Engineering,
Teerthanker Mahaveer University, Moradabad, Uttar Pradesh, INDIA
Email id: pavan.engineering@tmu.ac.in

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ABSTRACT

Wave Energy Converters (WECs) are equipment that converts movable mechanical or electrical electric energy into kinetic and potential energy from a moving sea wave. Ocean waves are a vast, mostly unexplored energy resource, with significant potential for energy extraction. The necessity to fulfill renewable energy goals drives research in this field, although it is still in its infancy compared to other renewable energy technologies. This study discusses the current state of wave energy and assesses the device types that reflect current wave energy converter (WEC) technology, with a special emphasis on work being done in the UK. The potential power take-off systems are defined, and several control methods to improve the efficiency of point absorber-type WECs are considered. There is a lack of consensus on the optimal technique for collecting energy from waves, and although past innovation has mostly concentrated on the idea and design of the main interface, concerns about how to optimize the power train have arisen. The essay ends with some predictions for the future.

KEYWORDS: *Energy, Power Generation, Technology, Wave Energy, Wave Power.*

1. INTRODUCTION

With the world's attention now focused on climate change and increasing CO2 levels, producing energy from renewable sources is once again a hot topic of study. The world's potential wave power resource is projected to be 2TW, with the UK's practical potential being 7–10GW. To put these numbers in context, the United Kingdom's entire grid capacity is 80 GW, with peak demand stabilizing at approximately 65 GW. As a result, wave energy may meet up to 15% of present UK power demand; when coupled with tidal stream production, up to 20% of UK need might be satisfied. To achieve the advantages mentioned above, a number of technological difficulties must be solved in order to improve the performance of wave power devices and therefore their commercial viability in the global energy market. Converting the slow (0.1Hz), unpredictable, and high-force oscillatory motion into usable motion to operate a generator with output quality suitable to the utility network is a major problem(1–3).

The power levels of waves vary in proportion to their height and period. While gross average power levels may be anticipated ahead of time, this variable input must be transformed into smooth electrical output, which typically requires the use of an energy storage system or other compensating equipment. Furthermore, wave direction is extremely changeable in offshore areas, thus wave devices must align themselves appropriately on compliant moorings, or be symmetrical, in order to collect the wave's energy. Because of the natural processes of refraction and reflection, the orientations of waves near the coast may be predicted in advance to a considerable extent(4–6).

1.1. Benefits:

Using waves as a renewable energy source has a number of benefits over other energy production techniques, including the following:

- Among renewable energy sources, sea waves have the greatest energy density. Winds, in turn, are produced by solar energy, which produces waves. An average power flow intensity of 2–3kW/m2 of a vertical plane perpendicular to the direction of wave propagation immediately below the sea surface is converted from solar energy intensity of 0.1–0.3kW/m2 horizontal surface.
- Use has a little detrimental effect on the environment. Thorpe discusses the possible consequences and provides an estimate of a typical near shore device's life cycle emissions. Offshore devices, on the whole, have the least negative effect.
- Wave energy has a natural seasonal fluctuation that matches power consumption in temperate regions.
- Waves have the ability to travel long distances with little energy waste. Storms on the western side of the Atlantic Ocean will move westward, aided by prevailing westerly winds, to the western coast of Europe.

1.2. Location:

Shoreline devices offer the advantages of being near to the utility network, being simple to maintain, and having a lower risk of being destroyed in severe circumstances since waves are attenuated as they pass over shallow water. This leads to one of the drawbacks of shore-based devices: reduced wave power due to shallow water (which may be partly offset by natural energy concentration areas). The tidal range may be a problem as well. Furthermore, due to the nature of their location, site-specific criteria such as coastline geometry and geology, as well as the preservation of coastal beauty, devices cannot be developed for mass production(7–9).

1.2.1. Type

Despite the large variation in designs and concepts, WECs can be classified into three predominant types.

- Attenuator
- Point absorber
- Terminator

1.3. Submerged pressure differential:

The submerged pressure differential device is a submerged point absorber that works by using the pressure difference between wave crests and troughs above the device. It is made up of two major parts: a fixed air-filled cylindrical chamber on the seabed and a movable top cylinder. The water pressure above the device compresses the air inside the cylinder when a crest passes over it, pushing the top cylinder down. The water pressure on the apparatus drops as a trough goes by, and the top cylinder rises. Because it is completely submerged, this gadget is not subjected to the hazardous slamming pressures that floating devices are subjected to, and it has a lower aesthetic effect. However, device maintenance may be a problem. Because a portion of the device is connected to the seabed, these devices are usually found close to shore. The Archimedes Wave Swing, an artist's impression, is an example of this gadget(10–13).

1.4. Oscillating wave surge converter:

An oscillating wave surge converter is made up of a hinged deflector (a terminator) that swings back and forth in response to the wave's horizontal particle velocity. The Aquamarine Power Oyster, a nearshore device with the top of the deflector above the water surface and hinged from the sea bottom, is an example. This gadget has been built as a prototype(14,15).

1.5. Overtopping device:

An overtopping device collects sea water from incident waves in a reservoir above sea level, then pumps it back out to sea through turbines. The Wave Dragonis an example of such a gadget. A pair of huge curving reflectors collect waves in the center receiving section, where they flow up a ramp and over the top into an elevated reservoir, from which the water is permitted to return to the sea through a number of low-head turbines.

1.5.1. Wave energy projects and organizations:

The list below covers some of the current wave energy initiatives, along with connections to UK institutions and businesses. Although the following organizations and projects concentrate on technical content, there are a number of additional wave energy organizations and initiatives that focus on promotion, economics, marketing, and other elements to help accelerate the adoption of marine energy.

- *EMEC:* The European Maritime Energy Centre (EMEC) was founded in 2003 with some financing from the Carbon Trust, with the goal of stimulating and accelerating the development of marine power devices, first via the operation of a testing facility in Orkney. The EMEC facilities, like the Wave Hub project, are test berths with electrical connections that allow wave energy device inventors to test full-scale prototypes.
- *EquiMar:* The Equifax Project (Equitable Testing and Evaluation of Marine Energy Extraction Devices in Terms of Performance, Cost, and Environmental Impact) is an FP7-funded collaborative research and development project involving a consortium of 23 partners that will run for three years starting on April 15, 2008. ‘Deliver a set of procedures for the fair assessment of maritime energy converters,' says the EquiMar project. These methods will standardize testing and assessment across a broad range of devices. These guidelines will serve as a foundation for future maritime energy regulations. Reference contains further information about this project.
- *Marine Energy Accelerator:* The Carbon Trust's current Marine Energy Accelerator is a project aimed at lowering the prices of marine energy technology and accelerating the period when these devices may help decrease emissions. It is a follow-up to the Marine Energy Challenge, which aided in the development and understanding of wave and tidal stream energy technology.

1.6. Power take Off Methods:

Energy capture methods vary per device, but with the exception of linear electrical production (described below), the most common way of generating electrical power is via high-speed rotary electrical generators. One of the most difficult aspects of WECs is determining how to power these generators. Heaving- and nodding-type devices aren't compatible with traditional rotating electrical machines, therefore a transmission system is needed to connect the WEC to the generator(16).

1.6.1. Rotary Generator Types:

On-line synchronous generators (SGs) are used in traditional power plants, and they run at a nearly constant speed, matching the frequency of the grid connection. Wave energy producers may have to deal with changing speed depending on the conversion mechanism. Doubly fed induction generators (DFIG), squirrel cage induction generators (SCIG), permanent magnet SGs, and field would SGs are the four kinds of generators discovered(17).

1.6.2. Turbine transfer:

The phrase ‘turbine transfer' refers to the technique utilized in systems in which a fluid flow (either sea water or air) powers a turbine that is directly connected to a generator. The usage of seawater turbines has the major benefit of causing no environmental issues due to fluid leakage. Sea water, on the other hand, is a complicated fluid with a variety of unexpected components(18). Abrasive particles may also harm seals and valves in nearshore equipment. Unless the turbine is in deep water to maintain positive pressure, cavitation may be an issue. Propeller-type turbines, such as the Kaplan design, are often employed in low-pressure conditions, as seen in overtopping devices.

1.6.3. Hydraulics:

A hydraulic system is another option for translating the main WEC interface's low-speed oscillating motion. Large forces are applied at moderate rates by waves, and hydraulic systems are ideally adapted to absorb this energy. Hydraulics working at 400bar pressure are a major benefit of certain kinds of WEC when size and weight are concerns, and the force generated by these pressures is much higher than that generated by the finest electrical machines.

1.6.4. Sealing:

Fluid confinement is related to the problem of sealing. Standard dynamic seals, on the other hand, are intended to function at lesser velocities than a normal WEC. Seal wear is exacerbated by temperature rises produced by shear loss and friction at the moving contact; the life of the seal is inversely proportional to the speed, distance, and length of its application, which has an effect on maintenance needs. The absence of "land-based demand" for high-velocity seals, rather than any technological problem, is said to be the cause of the seals' high-speed troubles.

1.7. Efficiency:

The PTO system's efficiency is critical to the device's capacity to capture energy. Coupled variable displacement pumps and motors, which have an optimum operating point and a peak efficiency of approximately 80%, are often used in traditional hydrostatic gearboxes. Efficiency decreases as you go away from this optimum operating position, and part-load losses (such as coulomb and viscous friction, leakage, and compressibility) become substantial. Although the hydraulic system may have a high rating, it is likely that the device will operate at a fraction of that rating for the most of the time, necessitating the greatest part-load efficiency(19–21). The DTI study also emphasizes hydraulics' efficiency problem, suggesting that effort be focused on developing specialized hydraulic motors with minimal part load losses and high torque pumps. Furthermore, the pressure drops associated with the orifices of the check valves used to correct the flow and the throttling valve used to regulate the flow result in a loss of power and decreased efficiency.

1.8. Maintenance:

Maintenance in the maritime environment is costly, time-consuming, and fraught with dangers. There are likely to be many steps between the principal interface and the electrical generator in a hydraulic conversion system, each with moving components and therefore requiring maintenance. It's critical that the amount of needed maintenance be kept to a minimum, with inspections required just once a year or fewer. Metal surfaces and components must also be kept free of corrosion and erosion. Ceramic coatings (such as Bosch Rexroth's Ceramax) are a potential way to protect components that come into direct contact with sea water.

1.9. End-stop:

The end-stop problem isn't limited to devices with hydraulic PTOs; it affects all moving body converters with stiff PTO connections. The oscillating interface exceeds its design travel, causing the issue. The oscillating interface may be linked to linear hydraulic rams that pump fluid to the motor via a hydraulic transfer system. The enormous forces and associated energy encountered in severe circumstances cannot be absorbed quickly by striking the cylinder stroke's end, causing the system to be damaged. The use of high-stroke actuators to mitigate this is limited by their bulk and cost, and their stroke capability will be underutilized most of the time. Buckling of extended stroke actuators is also a possibility, especially if side stresses are present at full extension.

1.10. Energy storage:

Because the variations in absorbed wave power result in highly variable electrical power production, which is inappropriate for the grid, most PTO systems include some kind of energy storage. As part of the hydraulic system, accumulators may serve as short-term energy storage. Accumulators assist the system cope with large levels of variation by storing energy, lowering the capital cost and power losses of all following powertrain components. Accumulators are used in the Pelam hydraulic PTO system to give a ‘smooth' flow to the hydraulic motors and to separate the main transmission (hydraulic cylinders and controls) from the secondary transmission (gearbox) (hydraulic motors and electric generators). This separation, it is said, enables for effective absorption across a wide range of incoming power; up to 80% absorption has been observed.

1.11. Reactive loading control:

On each side of the resonant frequency, reactive loading management is utilized to increase the efficiency range of a WEC. Adjusting the dynamic characteristics of the main converter, such as the spring constant, inertia, and energy absorbing damping, to allow optimum energy absorption at all frequencies, is a theoretically ideal control approach. Korde looked into reactive control in the context of velocity feedback and discovered that it could be used to modify the damping coefficient supplied by the PTO system to balance the device's radiation damping and allow for maximum allowable energy absorption. The main converter must experience no reactive force (as at resonance) and the energy absorption rate (damping) must match the rate at which kinetic energy is emitted from the device for optimal power absorption. To counteract part of the unwanted stiffness or inertia, reactive loading adds a phase change into the PTO force. The wave force deflects the device’s ‘spring' (a semi-submerged float mimics a spring) on either side of the resonant frequency, or accelerates the inertia, decreasing overall efficiency. When the force is in phase with the device's velocity, as it is at resonance, maximum efficiency is obtained.

2. DISCUSSION

Wave energy has a lot of promise in terms of producing power. The ocean is a vast resource, and capturing the energy contained in ocean waves is a critical step toward achieving renewable energy goals. The present state of WEC technology is discussed in this review. The various device kinds are identified and assessed. Institutions and businesses engaged in the development of WEC, as well as joint wave energy initiatives, are all included. Hydraulic, linear electrical generator, and turbine-based PTO systems are evaluated and categorized. A hydraulic PTO system is very well adapted to absorbing energy from a high force, slow oscillatory motion and may help convert reciprocating motion to rotational motion for driving a generator. However, there are a number of design issues to consider, such as efficiency and dependability. A linear electrical generator offers an alternative, although the technology is still in its infancy.

3. CONCLUSION

Active control of a WEC may greatly improve its efficiency and, as a result, its cost effectiveness. Latching control is being emphasized as a potential, easy way of effectively collecting energy in this study, which is presently continuing. Despite much study and development, the ideas for turning a low-high-force reciprocating motion into one that can generate electricity show no indications of convergence. There are questions about which idea to employ, how to improve its performance, and how to manage such a system. Future research should adopt a systems engineering approach, since the various subsystems of a WEC are all intertwined, and no one should be optimized without taking into account the others. Furthermore, since individual WECs will often function as part of a wave farm, future systems analysis must account for device interaction.

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