Renewable Electric Energy Systems EE—546

Marine Power Generation

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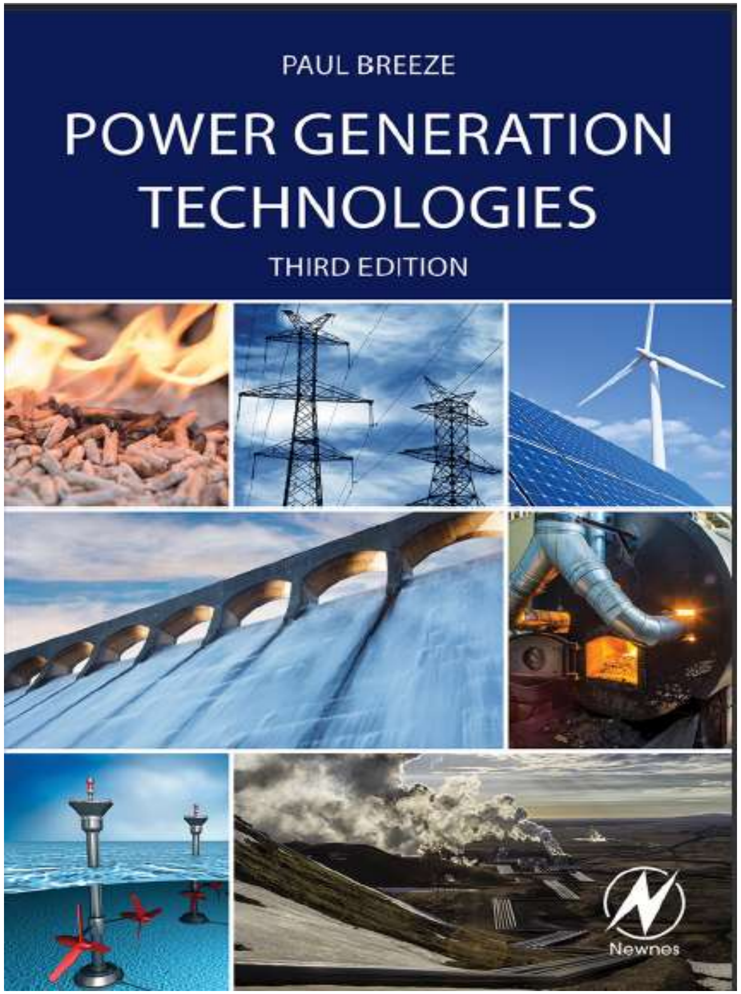
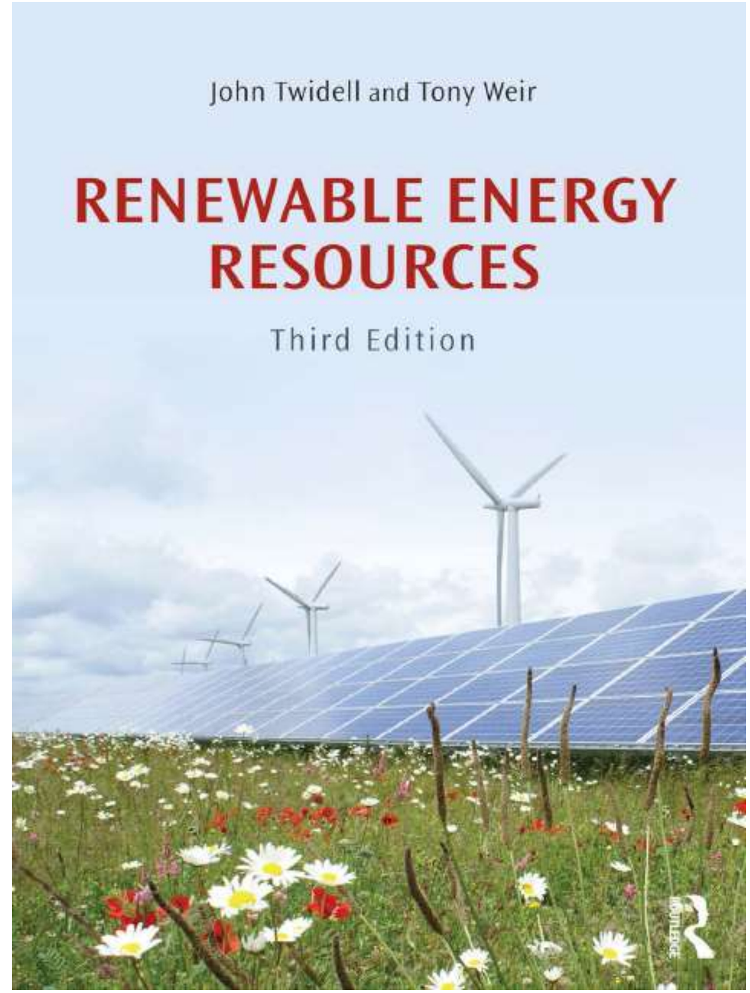
Marine Power Generation: Slides are prepared from-



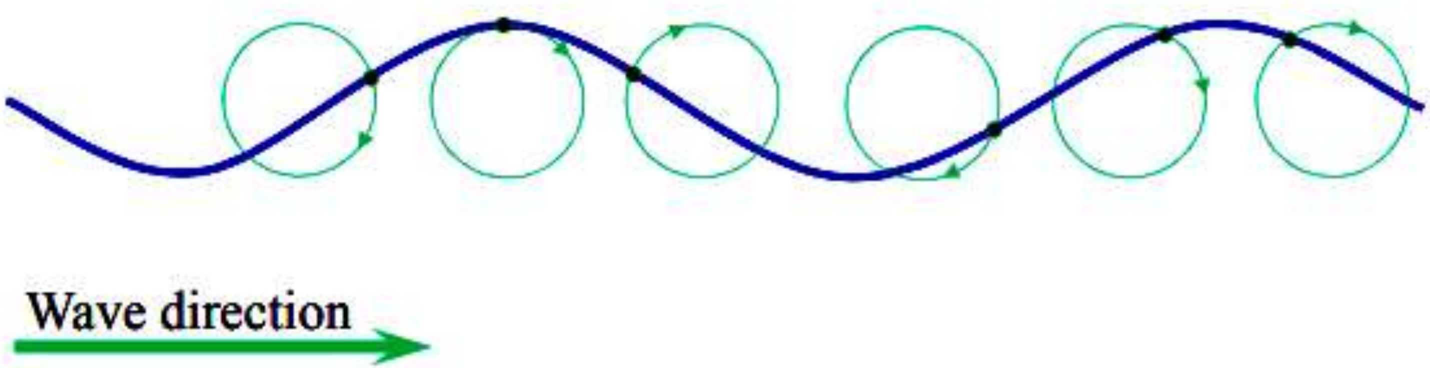


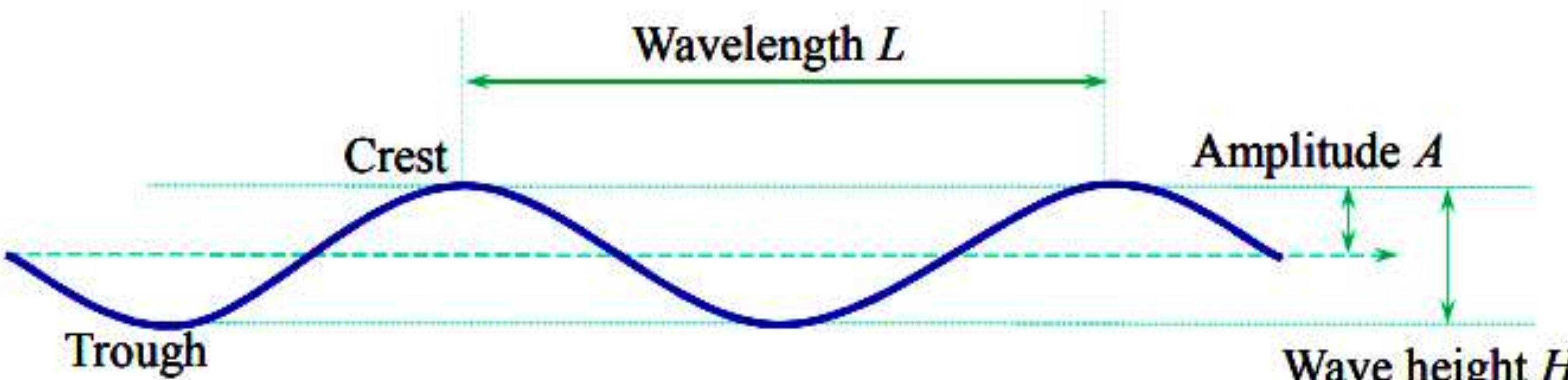
Paul Breeze—Power Generation Technologies (3rd Ed, 2019, Newnes)

John Twidell and Tony Weir—Renewable Energy Resources

How to describe a wave

Snapshot of the water surface at a certain instant:





Introduction: challenges facing wave power developments

1. Wave patterns are irregular in amplitude, phase and direction.
2. There is always a probability of strong hurricanes producing waves of large intensity. Commonly, the 50-year peak wave is 10 times the height of the average wave. Thus the structures have to survive in seas with ~100 times the power intensity.
3. Peak power is generally available in deep-water waves. The difficulties of constructing power devices for these types of wave regimes, of maintaining and fixing them and transmitting power to land, are difficult.
4. Wave periods are commonly ~5 to 10 s (frequency ~0.1 Hz). It is challenging to couple this irregular slow motion for electricity generation at ~500 times greater frequency.
5. Many types of device have been suggested for wave-power extraction and so the task of selecting and developing a particular method has been somewhat arbitrary.
6. The development and application of wave power have occurred with irregular and changing government interest, largely without the benefit of market incentives.

The Marine Energy Resource

TABLE 14.1 Marine Energy Resources

Marine Energy Resource	Potential Annual Energy Available	Potential Generating Capacity
Tidal current	800 TWh/y	5000 GW
Wave power	80,000 TWh/y	1000–10,000 GW
Ocean thermal energy technology	10,000 TWh/y	2600 GW
Salinity gradient	2000 TWh/y	2000 GW

Source: International Energy Agency[1]; Powertech Labs[2]

Wave Power

In deep water where the water depth is larger than half the wavelength, the wave energy flux is

$$P' = \frac{\rho g^2 H^2 T}{32\pi} \propto H^2 T$$

where ***H*** the trough to crest height, with ***P'*** the wave energy flux per unit of wave-crest length, ***T*** the wave energy period, ***ρ*** the water density and ***g*** the acceleration by gravity.

Example: Consider moderate ocean wave in deep water, with a wave height of 3 m and a wave energy period of 8 s. Using the formula to solve for power, we get

$$P \approx 0.5 \frac{\mathrm{kW}}{\mathrm{m}^3 \cdot \mathrm{s}} (3 \cdot \mathrm{m})^2 (8 \cdot \mathrm{s}) \approx 36 \frac{\mathrm{kW}}{\mathrm{m}},$$

meaning there are 36 kilowatts of power potential per meter of wave crest. In major storms, the largest waves offshore are about 15 meters high and have a period of about 15 seconds. According to the above formula, such waves carry about 1.7 MW of power across each metre of wavefront.

Wave Power

The waves found in seas and oceans are created when the sea absorbs energy from the wind. The stronger the wind and the longer the reach of sea over which it has to blow, the greater the amount of energy that is absorbed. The best wave regimes are generally found on western shorelines exposed to the wide ocean. The strongest winds are between 30 and 60 of latitude in both the north and the south of the globe, and these winds, blowing across the world's oceans, give rise to the largest wave energies.

The energy contained within waves is manifested as an oscillatory motion of the sea surface. Over very long reaches this can assume a regular frequency, as characterized by the swell found on the oceans, but often and particularly near the coast it will become a superposition of a number of different frequencies. Whatever it's precise nature, the motion from the point of view of energy capture is an oscillation of the water surface relative to a fixed point on land or on the seabed. It is this motion that must be exploited in a wave energy converter.

Wave Power Technology

The search to exploit the oscillatory motion of waves has given birth to a range of mechanical devices designed to convert that motion into electricity.

1 **Shore And Near—shore Wave Converters**

2 **Offshore Devices**

Oscillating Water Columns

Shore And Near—shore Wave Converters

One of the simplest and most common methods of capturing energy from wave motion is with an OWC device. This comprises a tube or chamber that has a lower aperture below sea level and the opposite end above sea level, open to the air. The simplest way of imagining an OWC is to think of a tube with one end immersed in the sea. As waves pass across the tube, the water level within it will rise and fall, alternately forcing air from the top of the tube or sucking it in. This motion of air can be harnessed to turn a type of wind turbine, generating electricity.

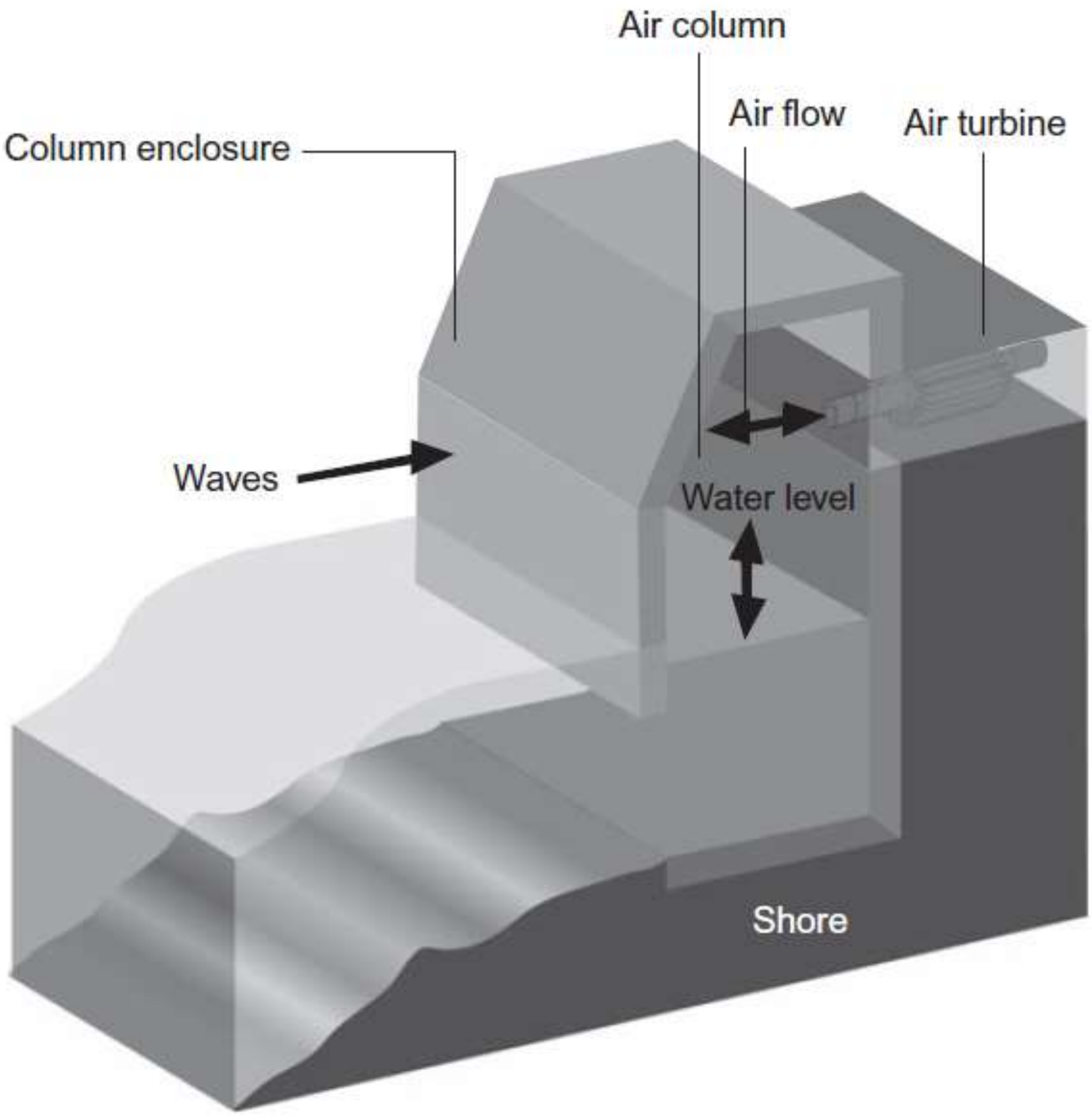


FIGURE 14.4 A schematic of a shore-mounted OWC wave energy converter.

Overtopping Devices and Tapered Channels

Shore And Near—shore Wave Converters

Another simple method for extracting energy from waves is to consider them simply as a variable head of water. If some of the water from the crests of waves can be captured, it can be used to create a head of water that rises above the surrounding sea level and this can then be exploited to drive a hydro turbine and generate power with the water from within the device running back to the sea (see Figure 14.5).

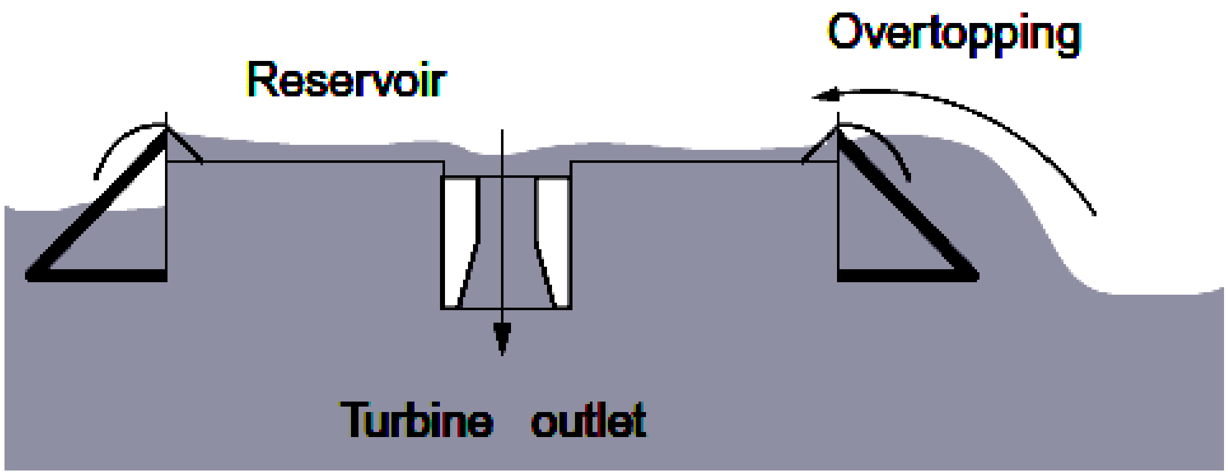


FIGURE 14.5 Schematic view of an overtopping wave energy device. *Eric Frűs-Madsen.*

Oscillating Flaps

Shore And Near—shore Wave Converters

A third common near-shore wave energy converter is the oscillating flap device, sometimes also called an inverted pendulum converter. The basic principle behind this type of converter is to devise a buoyant flap, the bottom of which is hinged and attached to a foundation anchored to the seabed. The body of the flap then rises underwater above the hinge. As waves move across the site of the device, they cause the flap to oscillate backwards and forwards and this oscillatory motion is converted into electrical power.

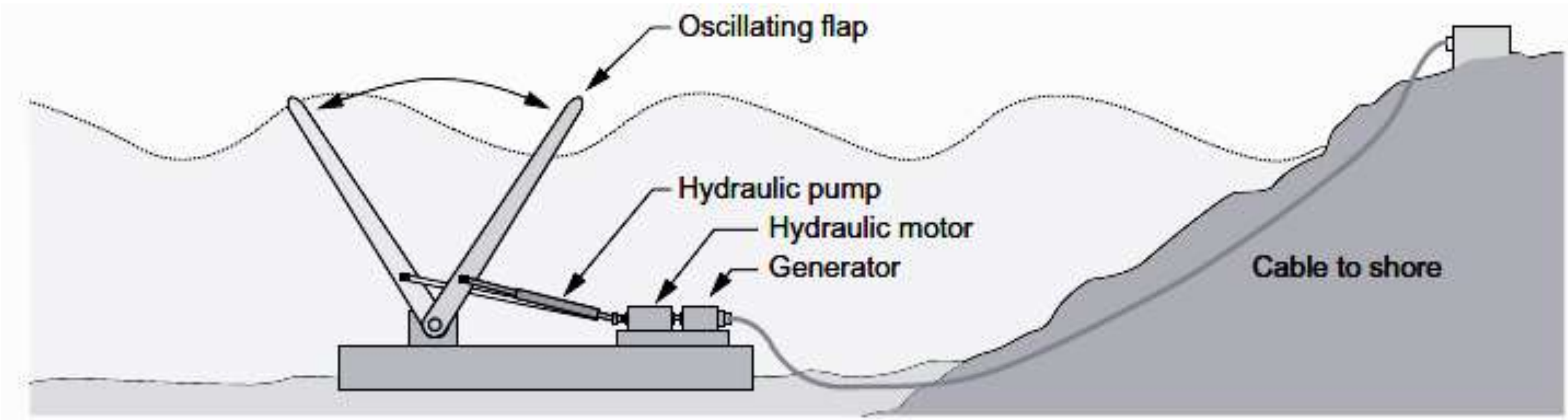


FIGURE 14.6 Oscillating flap wave energy converter. *OpenEI*[4]

Buoyancy-Based Devices (*offshore devices)*

One of the principal categories of offshore wave energy converters is based on a floating device such as a buoy which is tethered to the seabed. Although such devices can operate close to shore, because the energy contained in waves is greater far offshore, they are better deployed in deep water.

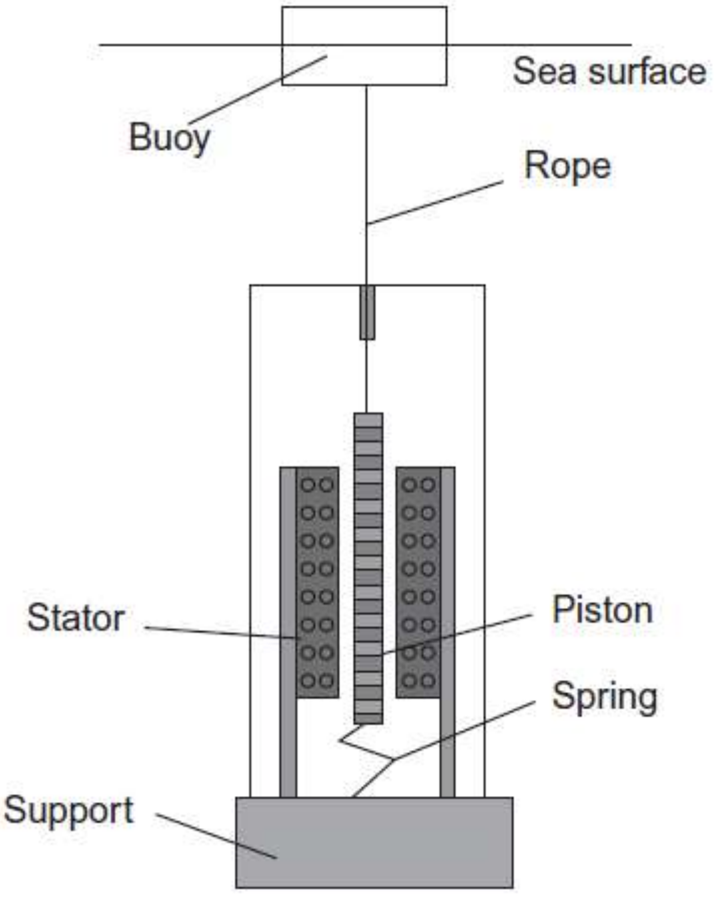


FIGURE 14.7 Floating wave energy converter with a linear generator.

Pontoons, Snakes and Ducks (*offshore devices)*

The second principal category of offshore wave energy converters comprises a disparate group of machines that have one thing in common. Each is made up of a number of floating sections that are joined end to end through a hydraulic linkage.

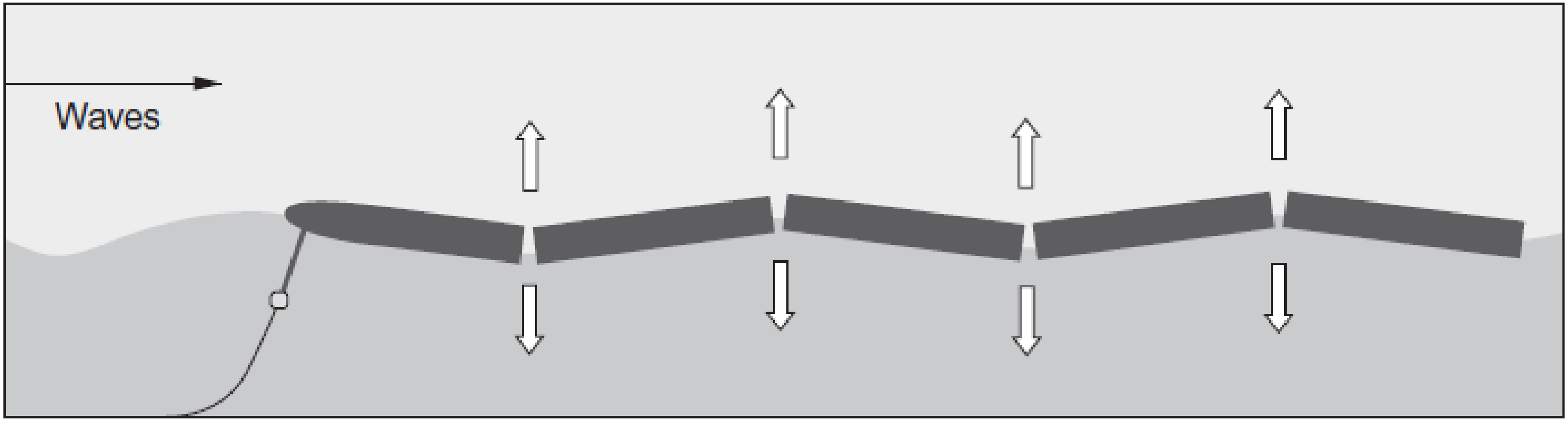


FIGURE 14.8 The action of the waves on the hinged sections of a floating wave energy converter.

Piezoelectric Devices (***offshore devices)***

Piezoelectric materials produce an electric voltage when they are placed under stress. This may be as a result of bending, of stretching or be caused by a variety of other means including when the material is subjected to vibrations. Any and all of these means of generating electricity could potentially be exploited in a wave energy device.

Marine Current Energy

Marine current converters, sometimes also called tidal stream converters, utilize the energy contained in flowing water generated by the motion of the world’s tides as a source of electrical power.

The amount of energy that is available in a marine current depends upon both the amount of water that is moving and the speed at which it flows.

Areas where there is a large tidal reach are likely to offer the best marine current potential because the volume of water moving on each tide will be large. Meanwhile, the faster that water flows, the greater the energy it contains.

Marine Current Energy Converters

Horizontal Axis Turbines

A horizontal axis marine turbine will often share many features with a horizontal axis wind turbine. A typical device may have a three-bladed rotor mounted on a shaft which drives a generator through a gearbox. Because it will be operating under water, all the electrical and mechanical components must be protected in a watertight container. Gearboxes have been notorious as a point of weakness in wind turbines and designers have developed direct drive systems that eliminate them. Similar systems can be applied to marine turbines. Variable speed generators have also been deployed in the wind industry, with electronic AC-DC-AC converters to match the output to grid frequency. Again these are becoming common within the marine industry.

Horizontal Axis Turbines

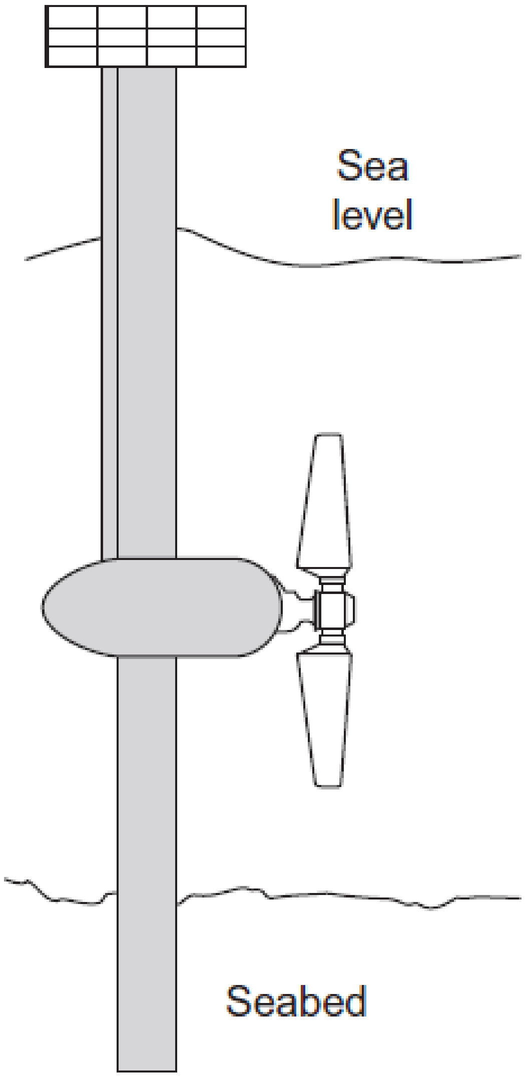


FIGURE 14.9 Schematic of a horizontal axis turbine, marine current converter.

Vertical Axis Turbines

A vertical axis turbine has its blades mounted onto a vertical shaft. The vertical axis design has two significant advantages. The first is that it will rotate in the same sense, whatever direction the water flows. The second is that its generator can be mounted at the top or at the bottom of the shaft.

The insensitivity to flow direction means that a vertical axis turbine will operate efficiently in a tidal region where the flow reverses twice a day. It will also be unaffected by cross-flows that might reduce the efficiency of a horizontal axis turbine. Depending upon the site, this could prove a great advantage. Meanwhile the ability to mount the generator at either end of the shaft means that it can be placed either on the sea or river bed or, more usefully, it can be deployed above sea level either from a shaft extending beyond the sea or on a floating support.

Vertical Axis Turbines

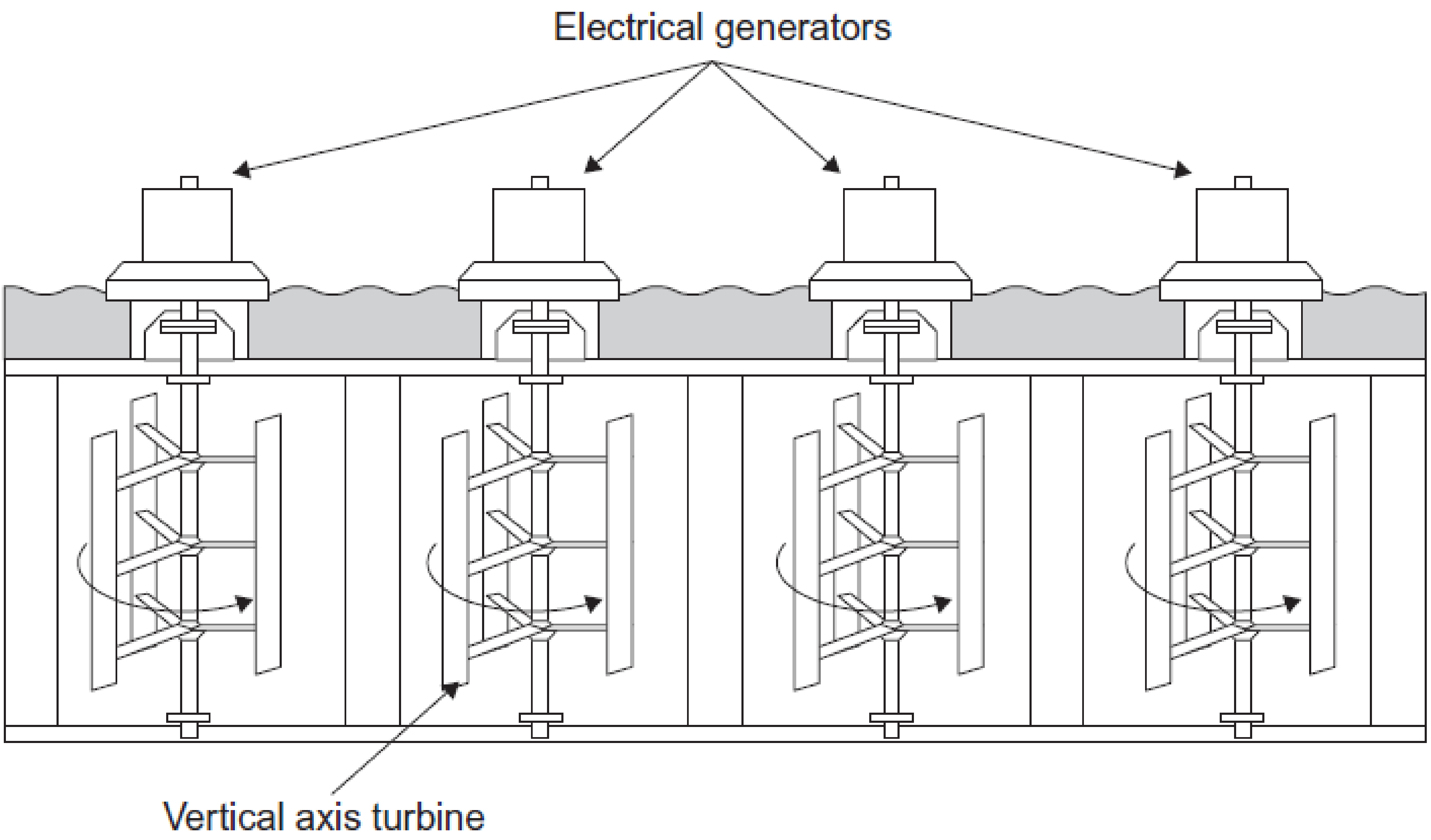


FIGURE 14.10 An array of vertical axis marine current converters.

Other Marine Current Devices

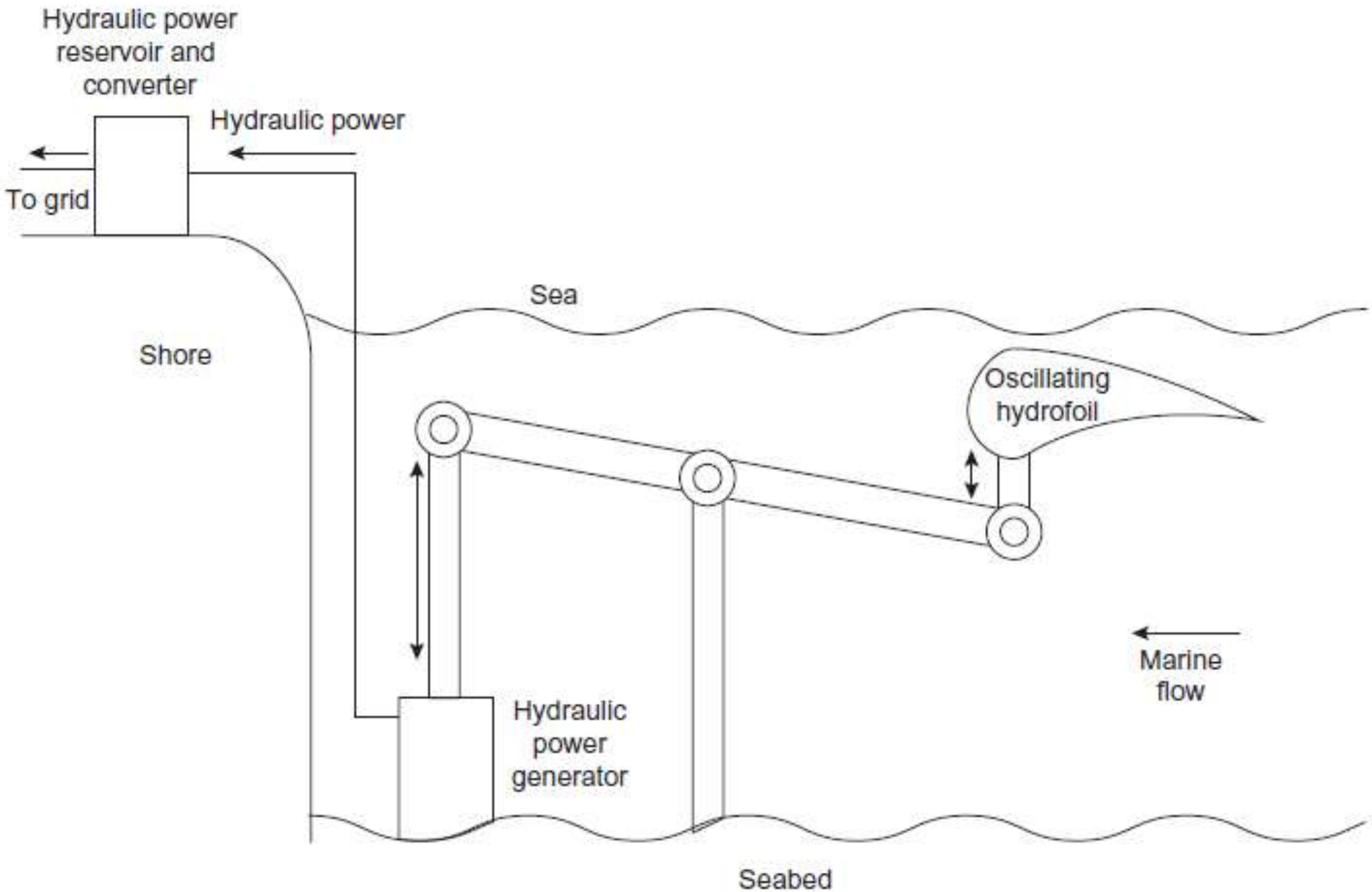


FIGURE 14.11 Schematic of an oscillating hydrofoil marine current converter with hydraulic power transmission.

Marine Power Fed to Grid

End of Marine Power Generation—Course Work