Hydraulic power take off system for wave energy utilization

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Abstract. Wave energy from seas and oceans is among the most promising and abundant energy sources on the Earth. There are different designs of conversion systems for the utilization of the wave energy, resulting from the different ways of the wave energy absorption, and depending on the location characteristics. The paper proposes a new hydraulic power take-off system (PTOS) that can be used in various types of wave energy conversion systems.

1. Introduction

The energy from the tides is inexhaustible and environmentally friendly, but it requires a serious investment to build a tidal power plant. Its technology requires connections to the power grid. Also, tides are not a constant phenomenon; they occur over some time. All these are among the reasons why tidal energy is still not fully utilized. However, according to scientific reports, tidal energy has great potential to thrive in the world of alternative renewables.

Different concepts for wave energy conversion (WEC) exist; over 1000 WEC techniques have been patented in Japan, North America, and Europe. Despite the considerable variation in design, WEC systems are generally categorized by location and type \cite{1-3}.

The energy power take-off subsystem (PTOS) of each wind-wave energy converter (WWEC) is defined as the mechanism by which the energy absorbed by the primary converter is transformed into electricity. The primary wave energy converter (PWEC) can be, for example, a chamber with an oscillating water column or a point absorber – buoy, floating platform. PTOS is of great importance for any WWEC, as it directly affects not only the efficiency of the conversion of the absorbed energy into electricity, but also preconditions the size, mass, and structural dynamics of the wind energy converter.

Through its direct impact on all components of WWEC and on its operation (figure 1), PTOS also influences the total average costs for electricity generation \cite{4}. The characteristics of PTOS affect the efficiency of converting the energy of the waves, and consequently – the annual amount of energy produced. PTOS has an immediate effect on the capital costs of WWEC, as its relative quota is about 20-30\% \cite{5}. The reliability of the PSOE determines the annual availability of WWEC, i.e., the energy produced and the operating and maintenance costs \cite{4}.
There are many PTOS types, and the choice of PTOS for a particular WWEC is of crucial importance. The systematic comparison of the different PTOS types is difficult, however, for at least two reasons:

- the limited amount of available data;
- a particular PTOS can be used in a maximum of two types of WWEC.

Five main types of PTOS are applied to convert sea waves' energy into electricity under real conditions: air turbines, water turbines, hydraulic converters, direct mechanical converters, and direct electrical converters.

The paper aims to present a new version of a hydraulic station for converting the sea wave energy. The principle of hydraulic converters is presented. The main ways to convert the energy of the sea and ocean waves into electricity are discussed. The proposed hydraulic scheme is described in detail.

2. Hydraulic converters

When PWEC is based on the direct motion of a solid body by waves, as in the case of point absorber and retarder, the conventional rotary generators are not directly applicable, and an intermediate element is needed: most often a hydraulic converter. The hydraulic converter is used effectively in low-frequency periodic impacts with high forces. In this situation, the direction of energy movement is the opposite of that of the hydraulic drive systems. The energy of the wave-driven solid body increases the pressure of the working fluid in the hydraulic system, which supplies a hydraulic motor, to whose rotor the electric generator is connected.

A diagram of a PTOS with a hydraulic converter is presented in figure 2. In this case, a point absorber (buoy, float), firmly connected to the piston of a hydraulic cylinder, is used as a PWEC. Under the action of the waves, the point absorber and the piston in the hydraulic cylinder respectively, move reciprocating, and the working fluid moves in a closed circular circuit from the hydraulic cylinder to the hydraulic motor and vice versa. Hydraulic accumulators for high and low pressure are included to reduce the pressure pulsations of the working fluid at the inlet and outlet of the hydraulic
motor. Rotary radial-piston hydraulic motors are most often used for PTOS with a hydraulic converter, as their behaviour in low-speed, high-load applications have been thoroughly studied.

Figure 2. Exemplary scheme of PTOS with a hydraulic converter: 1 – Hydraulic motor, 2 – Generator, 3 – Low-pressure accumulator 4 – Actuator, 5 – Buoy, 6 – High-pressure accumulator, 7 – Check valves.

The use of PTOS with a hydraulic converter is associated with solving some specific problems, which have to be considered when designing a PTOS with a hydraulic converter.

The hydraulic system elements must be carefully selected in terms of their performance and efficiency both individually and as a system, as well as in terms of the environmental impact of the system. Due to the change of the sea waves energy in a wide range, gas accumulators must be included in the hydraulic system to absorb energy at peak moments and smooth out the pressure change at the inlet of the hydraulic motor. Rotary radial-piston hydraulic motors with digital control [6] have been developed to increase their efficiency under partial load and to facilitate their control [7]. The hydraulic converters have many moving parts, and the piston seals wear out during operation, which can substantially increase the maintenance costs. Attention must also be paid to the PTOS protection in extreme conditions, when the stroke of the piston may exceed its design value and destroy the system. One possible solution is to provide a piston stroke limiter [8] or to use a radial hydraulic piston [9].

3. Direct mechanical converters
The schematic diagram of PTOS with the direct mechanical conversion of the wave energy into electricity is presented in figure 3. The mechanical energy of a wave-driven oscillating solid body (buoy) is converted into electrical energy using an additional mechanical fitting that drives a rotary generator. This mechanical fitting can be a gearbox, reels, and ropes. The rotary mechanical fittings usually include a flywheel to accumulate or release energy to smooth out short-term changes in the wave energy.

One of the advantages of this PTOS type is that the wave energy conversion into electrical energy involves three steps: i.e., the energy of the waves is converted into mechanical energy of the body, which is transformed into mechanical energy of the shaft, which in turn is transmuted into electrical energy. On the other hand, the mechanical converter performs countless operating cycles, and its reliability needs to be checked and proven.
4. Direct electrical converters

Advances in both the technology for permanent magnets production and power electronics have made the PTOS that directly convert the wave energy into electricity a desirable solution. A scheme of the PTOS is presented in figure 4. The energy of the reciprocating motion of a wave-driven solid body (buoy, float) is converted directly into electricity using a linear electric generator [10, 11]. A rod is attached to the bottom of the buoy. The head, which consists of an even number of permanent magnets, mounted one below the other, is in the lower part of the rod. Every two adjacent permanent magnets have the opposite polarity. The waves create a reciprocating motion of the rod, together with the head, which moves inside a stator. In the stator, the electric current is induced.

As a result, the wave energy is converted directly into alternating electric current, whose frequency and voltage are continually changing. Therefore, before connecting to the electrical network, it is needed to transform the alternating current into direct current firstly; then it is converted into alternating current with a given frequency and voltage, which can be done passively or actively [5]. It is required to constructively create and guarantee the existence of a minimum air gap between the rod head and the stator coil in all possible conditions.
5. New hydraulic system for converting the energy of the ocean and sea waves

New PTOSs are continually being created and studied, as the wave climate in the various water basins has characteristics that change in a wide range. As a result, there is no technology, which could be universally applied.

Figure 5 shows the design of a new hydraulic station to convert the energy of the ocean and sea waves into electricity.

![Figure 5](image_url)

**Figure 5.** The designed new system for wave energy conversion: 1 – electric motor, 2 – gear pump, 3 – hydraulic oil tank, 4 – 4/3 hydraulic road distributor with manual control, 5 – hydro motor, 6 – filter breather, 7 – suction (submersible) filter, 8 – safety overflow valve, 9 – backflow preventer valve, 10 – shut-off valve, 11 – pressure gauge, 12 – pressure filter, 13 – regulating throttle with backflow preventer valve for pipe installation.

The motor (1) is fitted on a P profile, which is welded to the tank (3) cover and is coupled to the gear pump (2) through a finger coupling with a rubber working body. On one side of the gear pump, the suction pipe is mounted through a flange connection, and the suction filter (7) is attached to it. On the other side of the gear pump, the inflator line is mounted again using a flange connection. The backflow preventer valve (9), the safety overflow valve (8), the shut-off valve (10), and the pressure gauge (11) are joined to the inflator line. The pressure filter and 4/3 hydraulic road distributor with manual control (4) are also assembled alongside the inflator pipeline. After the hydraulic distributor with manual control, two regulating throttles with a backflow preventer valve for pipe installation (13) are mounted. The hydraulic system is connected with the hydro-motor (5) through flexible hoses. The system is driven by the rotation of the electric motor, which provokes rotation of the gear pump through the finger coupling. The gear pump sucks the working fluid from the tank and injects it into the line under pressure. The safety overflow valve, installed immediately after the gear pump, is set to the maximum permissible operating pressure of the gear pump. The pressure gauge and the shut-off valve monitor the pressure in the inflator line. A pressure filter for purification of the working fluid...
and the backflow preventer valve are also installed on the pressure pipeline. After the hydraulic elements, the working fluid reaches the 4/3 hydraulic road distributor with manual control and the hydraulic motor, which must be driven. Two regulating throttles with a backflow preventer valve are mounted in the two directions of rotation to adjust the speed of the hydraulic motor.

6. Conclusion
The paper presents the main ways to convert the energy of the sea and ocean waves into electricity. A new hydraulic system for this type of conversion is proposed. The new system can be applied in all devices that consist of turbines used to capture the waves’ energy in real conditions.

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