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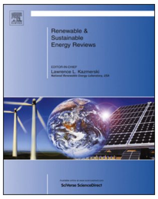

Electrical damping of linear generators for wave energy converters—A review

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ABSTRACT

The electrical damping of point-absorber wave energy converters is crucial to optimize the power output. Many circuit topologies have been proposed, but the possible increase in power absorption must be weighed against parameters such as cost, reliability and control system complexity. In this paper, the known electrical damping circuits are categorized, described and compared. The hydrodynamic damping of the buoy is covered, and how a linear generator can be used as a power take-off unit to apply a damping force. A qualitative comparison of the circuits is presented in the end. A more complex and costly power electronics system may be viable for wave energy converters (WECs) of large-scale power rating. However, for farm operation with small-scale WECs, a simpler and passive damping may be more suitable.

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1. Introduction

In the quest for harvesting renewable energy sources, the energy potential of the world's oceans have gained an increasing interest for the past two decades. Today, there are around 100 ongoing projects at various stages of development, and the number keeps increasing. A review on the most prominent technologies is found in [1]. There are various ways of categorizing the types of wave energy converter (WEC) devices, as first described by Hagerman [2]. The most popular of these is the categorization by method of absorbing the energy, where there are three categories: the overtopping device, the oscillating water column and the oscillating (activated) body. The last one can be further divided into three sub-categories, based upon the direction of the radiation force. These are the point-absorbers, the attenuators and the terminators. The point-absorber is defined as having a device width much smaller than the wavelength of the incoming waves. The power take-off (PTO) unit may be hydraulic, pneumatic or electric, and the PTO can either be floating, submerged or installed on the seabed. In this paper, the PTO with all-electric conversion using a linear generator (LG) is considered.

Among the point-absorber projects that have reached the stage of offshore device testing, the Uppsala University project [3,4] and the Oregon project [5,6] are both based on a floating buoy connected to a LG. The Archimedes Wave Swing (AWS) [7] is instead submerged below the sea level to utilize the pressure differences from the waves. The basic concept from Uppsala University is displayed in Fig. 1.

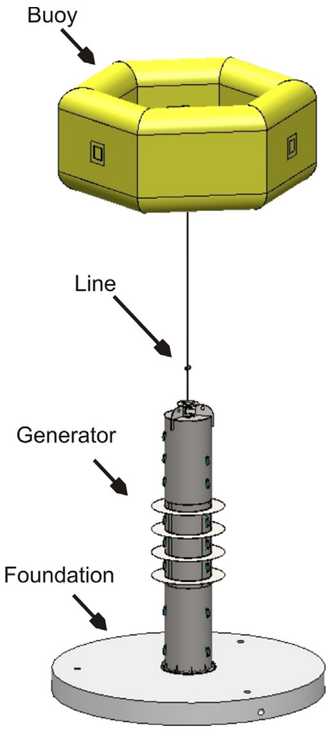

Fig. 1. Example of the point-absorber concept developed at Uppsala University. The floating buoy is moving in heave motion, and transfers the power to the linear generator on the sea bed. The translator of the generator is directly driven, without use of gearbox.

To make the point-absorber a viable alternative, the proper damping force has to be applied. Many point-absorber concepts are based on pneumatic or hydraulic damping, as described in [8]. The pressurized medium is then used together with a gearbox to drive a high-speed rotational generator. The drawback of a hydraulic PTO is high mechanical stress, losses in the different conversion stages and reduced reliability. As an alternative, the direct-driven linear generator has been suggested as PTO. This offers a more robust design with better conversion efficiency. However, the slow, reciprocating speed of translator results in relatively large units even at modest power levels. Also, the increased external forces require a mechanically very robust structure.

1.1. Control objectives

There can be several control objectives for a farm of aggregated point-absorber WECs. These include

1. Handle sudden extreme forces [9].
2. Maximum power point tracking (MPPT) of the individual WECs as well as the overall WEC farm [10].
3. Grid-connection control schemes of wave farms [11,12].

Most projects are still in the individual device testing stage, making MPPT a key research point. It is probable that lifetime studies and wave farm studies will increase in the near future. In this paper, electrical strategies for MPPT are in focus.

1.2. Different time scales of the control

If some active or passive control strategy is adapted for the WEC, it can be categorized by the time-scale of the control. The time range can be very wide, from seasonal variations to individual wave control:

- *Seasonal sea state fluctuations* [13]: It is possible to tune the WEC parameters for the dominant wave frequency and wave height, as discussed in [14].
- *Daily fluctuations*: The most prominent sea state changes with daily cycles are due to the tidal effects, which will have a great impact on the WEC power absorption [15]. One suggested technique to cope with this is developed in [16]. It is also possible to tune the natural frequency of the WEC by e.g. using water ballasts, as suggested in [17].
- *Hourly control*: This is more sensitive to the current sea state which may change in cycles of several hours or faster. Control in this time range is often referred to as slow tuning. The average sea state parameters are detected, and used as an input for the control strategy.
- *Wave-to-wave control*: This is a real-time control strategy, where an active damping is applied within the wave cycles.