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Control of offshore marine substation for grid-connection of a wave power farm

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ABSTRACT

To grid-connect an offshore wave power farm, an intermediate marine substation is suggested. As a part of the Uppsala University wave power project, a marine substation has been designed, assembled and deployed at sea. The substation is capable of connecting up to seven wave energy converters (WECs), and to transfer the power to the onshore 1 kV-grid. In this article, the control procedure for grid connection of the WECs is described step-by-step, and the practical implementations are presented. The system is designed with autonomous control and will connect or disconnect the WECs, depending on the sea state. Fault handling is taken into account, and grid power quality such as harmonic distortion and flicker are considered in the design. Experimental results are presented to verify the system functionalities.

1. Introduction

The global energy demand is continuously increasing, whereas the resources are limited and the environmental effects are a critical issue. The use of renewable energy sources, such as wind, solar and ocean energy, could provide the solution to this. While the extraction of wind and solar energy has increased exponentially for the last decade, ocean energy has not reached the commercial stage yet. The energy available in the oceans around the world is immense, and several wave energy

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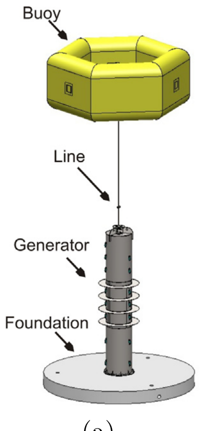
converter (WEC) prototypes have been developed during the last decades [1]. At the Centre for Renewable Electric Energy Conversion, Uppsala University, a WEC concept has been developed and experimentally verified [2,3]. The point-absorber type WEC, shown in Fig. 1(a), consists of a linear generator placed on the seabed, connected with a line to a buoy on the surface. The generator is of the direct-driven permanent magnet type, and only electrical damping is applied. The mechanical design is simple and robust to withstand violent sea states and increase the lifetime of the device. As the main characteristic of the point absorber is to have a buoy diameter much smaller than the wavelength of the waves, its capture width will be limited. To increase the total power absorbed from the sea, large clusters of WEC units have to be deployed, as illustrated in Fig. 1(b).

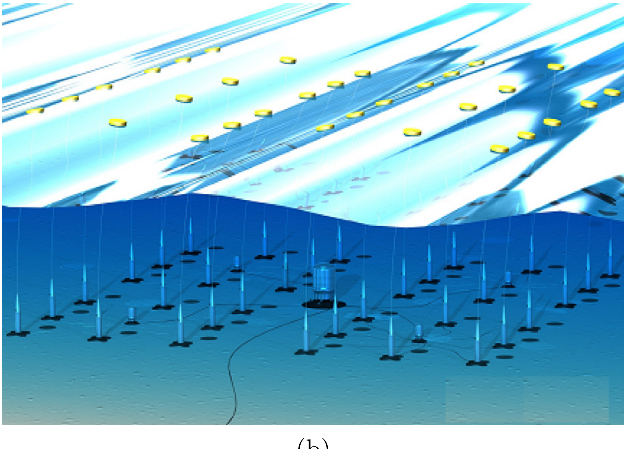
To reduce the number of sea cables from the offshore farm to the coastline, and to improve the transmission efficiency, an offshore marine substation is put on the seabed within the farm. The benefits of a seabed installation compared to a platform installation includes e.g. cost savings, easier and more reliable cable layout (no flexible cables required) and avoidance of extreme wave forces on the substation hull. The drawbacks include the difficult maintenance, pressurization and more expensive cable connections. These are discussed in more detail in [4].

The marine substation collects the cables from the WECs, and transfers the WEC powers to the electric grid onshore via a single sea cable. As a part of the Uppsala University project, a marine substation has been designed and assembled, as shown in Fig. 2(a). The substation was deployed during the summer of 2013 (Fig. 2(b)), for grid connection of seven WECs to the local onshore grid at a distance of 2.5 km. The substation has a power rating of 160 kW, and transfers the power using a three-phase 1 kV AC-link. A summary of both the mechanical and electrical layout is found in [4], and the onshore experimental verifications in [5].

The selection of transmission technology to shore depends on the electrical characteristics of the farm (power and voltage output) as well as the distance to a sufficiently strong grid point. In the end, the choice of power transfer type will be a compromise between capital expenditures (CapEx), operational expenditures (OpEx) and transmission efficiency. Experience from offshore wind farms shows that the CapEx may be in the range of 20–25% of the total farm investments [6]. Various cost factors for grid connection of wave power are discussed in [7]. To make these installations viable, the OpEx must be sufficiently low. For better utilization of the installed cable capacity, it has been suggested to combine offshore wind farms with wave farms [8]. Overviews of grid connection topologies in offshore installations are discussed in [9–11]. Alternative topologies, such as the cascaded H-bridge multilevel inverter (CHB-MLI), which is suitable for a farm with many isolated units, has been proposed in [12].



(a)



(b)

Fig. 1. (a) Point-absorbing wave energy converter. (b) Cluster of WECs connected to the marine substation.