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A new maximum power point tracking algorithm for ocean wave energy converters

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ABSTRACT

This paper describes a new maximum power point tracking (MPPT) algorithm developed to control a wave energy converter (WEC) in random seas. This algorithm, named the cycling MPPT algorithm, is compared to a perturb and observe algorithm described in numerous literature. Both algorithms were initially tested during 2012 ocean tests of the half-scale prototype Wave Energy Technology – New Zealand (WET-NZ) WEC off the Oregon coast. During these sea trials the perturb and observe algorithm failed to provide effective control of the WET-NZ, while the cycling algorithm was observed to give effective control. More complete investigations were later carried out using MATLAB-Simulink simulations of an autonomous WEC (AWEC) being developed at Oregon State University. The results of the AWEC simulations also showed the cycling algorithm provided better control than the perturb and observe algorithm. The operation of the cycling algorithm was fully characterized during the AWEC simulations and these results are presented.

1. Introduction

Ocean wave energy is an area of increasing interest, with a number of wave energy converter (WEC) prototypes being developed around the world. In order to facilitate the commercialization of marine energy technology, the Northwest National Marine Renewable Energy Center (NNMREC), headquartered at Oregon State University (OSU), is developing ocean test facilities that can be used by WEC developers to test their prototype devices. As part of that effort, NNMREC has developed the Ocean Sentinel instrumentation buoy, a 6-meter buoy that facilitates open-ocean, stand-alone testing of prototype, scale model WECs with average power outputs of up to 100 kW. The Ocean Sentinel is normally deployed at a Pacific Ocean test site that is located three miles offshore, near Newport, OR. When in use, the Ocean Sentinel is connected to the WEC being tested with an umbilical cable. Load banks on board the Ocean Sentinel dissipate power generated by the WEC. The Ocean Sentinel includes generator power conversion and control equipment that can provide an adjustable resistance load to the electrical generator of the WEC being tested using the Ocean Sentinel load banks. This allows testing of WECs that do not have their own generator power converter, so that prototype WECs in early stages of development can be tested. A detailed description of the Ocean Sentinel and its capabilities is included in [1], and a more detailed description of the Ocean Sentinel power conversion and control system is included in [2]. The Ocean Sentinel was deployed for the first time in August 2012 for a six-week period to test the experimental half-scale Wave Energy Technology New Zealand (WET-NZ) WEC.

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When the Ocean Sentinel power conversion and control system is used to operate a WEC during an ocean test, WEC control is provided by this equipment, which is operated by NNMREC staff. This has led NNMREC to work on developing WEC control methods that can be easily implemented in the Ocean Sentinel controller, in order to assist developers. One control method that NNMREC has investigated is maximum power point tracking (MPPT). MPPT has potential as an easily implemented control method that can adjust a control parameter to maximize the output power of a WEC being tested as sea conditions vary. MPPT is a common technique used to adjust the electrical loading applied to solar panels in order to maximize their power output. A survey of literature describing MPPT control of photovoltaic systems is provided in [3], where different MPPT control methods described in 91 reviewed papers are segregated into 11 primary methods. Perturb and observe MPPT methods are most commonly described in the reviewed literature, where the operating voltage of photovoltaic arrays are repeatedly perturbed and changes in array power observed to determine the direction of subsequent voltage adjustments. Different MPPT techniques have also been used to control wind turbines. In [4], the authors provide experimental results for a proposed small wind turbine control system that uses a perturb and observe algorithm to adjust the torque applied to the rotor based on observations of turbine output power. A similar MPPT method for control of rotor torque in utility scale wind turbines is described in [5].

The use of a simple "perturb and observe" MPPT method to control WECs was demonstrated during previous work at OSU. This work is described in [6]. A MPPT algorithm was used to control the electrical load applied by a power converter to the generator of a point absorber WEC. This WEC used a linear electrical generator, with the generator windings installed in a central spar and an outer section of permanent magnets installed in a toroidal float that moves up and down relative to the spar. The MPPT control was tested in a laboratory, where the generator components from the WEC were mounted in a Linear Test Bed at OSU that could move the permanent magnets relative to the fixed windings of the generator per preprogrammed time-based position profiles. The Linear Test Bed was programmed with a 15 min duration sea surface elevation recording made during an earlier WEC deployment. This allowed laboratory testing of the electrical generator with motions that mimicked ideal wave following motions of the WEC float relative to a fixed spar in the recorded sea conditions. Repeated experimental runs were performed with different settings of the MPPT algorithm. The results showed that 1) effective MPPT control of the generator load was possible, and 2) long MPPT iteration times with small control steps gave the best results. Although these results were promising, this testing was performed with the WEC generator only and did not include the effects of hydrodynamic forces on the WEC. This led to the follow-up work described in this paper being performed during the WET-NZ deployment with the Ocean Sentinel in 2012, and by computer simulations of an autonomous wave energy converter (AWEC) design that was developed at OSU.

During ocean testing of the WET-NZ, MPPT control was used to adjust the WET-NZ generator load resistance. The WET-NZ generator load resistance indirectly determines the load on the float through a hydraulic PTO, although unintended PTO power losses in the scaled device being tested made control more challenging. Initially, a perturb and observe algorithm similar to that tested previously at OSU [6] was used. Long MPPT iteration times were used because this had given the best results during the previous OSU tests. Erratic behavior was observed with this algorithm and it did not appear to provide effective control of the WET NZ. This led to the initial development and testing of a new "cycling" MPPT algorithm. The cycling MPPT algorithm gave better results. Due to the varying sea states that occurred and the limited test time available, however, it was not possible to systematically test the two MPPT algorithms and settings under the same sea conditions during the WEC-NZ deployment.

Following the WET-NZ tests, more thorough testing of both the perturb and observe and the cycling MPPT algorithms was performed using simulations of a small 200 W autonomous wave energy converter (AWEC) under development at OSU. Simulations of the WET-NZ were not feasible because that design is proprietary. Although the AWEC and the WET-NZ are both point absorber WECs, their geometry and PTO designs are quite different. The AWEC is a much smaller device that has a cylindrical float that slides up and down over a tubular spar to generate power from the heave motion of the waves. It has a direct-drive PTO that provides a direct linkage between the electrical generator and the float. The WET-NZ, by comparison, has a float that rotates with respect to the spar and allows power generation from both wave heave and surge and uses a hydraulic PTO to link the float to an electric generator. For this reason the WET-NZ ocean test and the AWEC simulations can't be directly compared, but represent separate tests of the algorithms with two different WEC designs. During simulations of the AWEC, a systematic investigation of the two MPPT algorithms was made with different settings. The results of the AWEC simulations showed that the new cycling MPPT algorithm provided better WEC control and was easier to implement than the perturb and observe algorithm.

2. MPPT algorithms investigated

Two MPPT algorithms were investigated during this work: 1) a perturb and observe algorithm similar to that demonstrated previously at OSU [6], and 2) a newly developed cycling algorithm. Both algorithms were configured to control the load resistance applied to the electrical generator in the PTO of point absorber WECs. Although these algorithms are described for that use here, both can be adapted for different purposes. During the WET-NZ tests, the Ocean Sentinel power converter was configured to provide passive rectified control of a permanent magnet (PM) ac generator, with the load resistance applied on the dc side of the generator rectifier. The AWEC also has a PM generator, and that device was simulated with