International Journal of Offshore and Polar Engineering
Vol. 12, No. 2, June 2002 (ISSN 1053-5381)

Optimum Control of Oscillation of Wave-Energy Converters

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ABSTRACT

The power output from wave-energy converters (WECs) may be increased by controlling the oscillation in order to approach an optimum interaction between the WEC and the incident wave. Optimally controlled WECs, designed to operate at full capacity a rather large fraction of their lifetime, may improve the economic prospects for wave power significantly. Most of the WECs discussed here utilise just one mode of oscillation. An upper bound is given to the ratio between the converted power from a given wave and the geometrical volume of the converter. One control strategy for maximising the converted power is based on measuring the incident wave, while another strategy utilises measurement of the WEC's own oscillation as input to the controller. In either case, the measured quantity has to be predicted some seconds into the future because of noncausal control functions.

INTRODUCTION

Most of the proposed devices for conversion of wave energy are oscillating systems with a frequency-dependent response showing the phenomenon of resonance. At resonance, that is, when the wave period agrees with the natural (eigen) period, the fraction of converted energy attains maximum. With wave periods off resonance, the conversion is less powerful, particularly so if the resonance bandwidth is narrow. Wave-energy converters (WECs) of large horizontal extension, so-called terminators and attenuators, have rather broad bandwidths, while point absorbers, for which the extension is very small compared to the predominant wavelength, have rather narrow bandwidth. On the other hand, an advantage with point absorbers is that the smaller the structural volume of the converter is, the larger the ratio between the potentially converted power and the mentioned volume (Budal and Falnes, 1980). With the reality of our wave climates, a point absorber would have to operate mostly off resonance. Hence, for a point absorber it is imperative that means are provided for optimum control of the oscillatory motion in order to achieve a maximum of power conversion. For larger conversion structures, such as terminators and attenuators, with their broader bandwidths, the benefit of applying optimal control may be more marginal (Greenhow et al., 1984).

When optimal control is desirable or needed, the first problem to resolve is the conditions for optimum. Second, we need to discuss the general principles: How to approach optimum. Third, designs have to be proposed and components developed in order to implement the optimal control in practice. The present review paper will mainly address the first two problems.

For real sea waves, contrary to sinusoidal waves, strict optimal control is not realisable. Then a somewhat suboptimal, but realisable, control procedure has to be adopted. In initial studies, optimal control was considered with regular (harmonic or sinusoidal) waves. The purpose of the control is then to obtain optimum phase and optimum amplitude of the oscillation in order to maximise the converted power. Optimum phase is obtained if the wave-absorbing oscillating system is in resonance with the wave. Subsequently, when optimal control was considered with real, irregular waves, the need for predicting the wave (some seconds into the future) became apparent. Since such prediction cannot be achieved to perfection, only a suboptimal control is realisable.

In the present review paper, we consider WECs which utilise several or only one oscillating mode of motion. We consider cases with unconstrained amplitudes as well as cases with constrained oscillation. Moreover, we shall discriminate between continuous control and discrete control. In the latter case, control actions can be made only at certain instants of the oscillation cycle.

SHORT HISTORICAL REVIEW

Use of control engineering to optimise wave energy conversion was proposed in the mid-1970s by Budal (Budal and Falnes, 1977, 1978) and independently by Salter (1980; Salter et al., 1976). For practical implementation, it was proposed to use a controllable power take-off device, for instance, a combined generator and motor. With this kind of continuous control, the aim is to achieve optimum phase and amplitude of the oscillation. Expressed differently, optimum phase control means to control the reactive power in order to maximise the active power. For this purpose, it may be necessary for the instantaneous power conversion through the power take-off device to be reversed during small fractions of the oscillation cycle. For this reason the term reactive control has been used (Salter, 1979) for continuous phase control.

Later, Budal proposed (Budal and Falnes, 1981; Falnes and Budal, 1978) that approximate optimum phase control may be conveniently achieved by latching the wave absorber in a fixed position during certain intervals of the oscillation cycle. With this method, proposed independently also by Jones (Guenther et al., 1979) and by French (1979), control action is made at discrete instants of the cycle. This is an alternative to the continuous phase control realised through a combined generator and motor, or turbine and pump. Compared to this continuous control method, the discrete control method is more suboptimal with unconstrained

Received September 13, 2001; revised manuscript received by the editors April 2, 2002. The original version (prior to the final revised manuscript) was presented at the 11th International Offshore and Polar Engineering Conference (ISOPE-2001), Stavanger, Norway, June 17–22, 2001.
KEY WORDS: Reactive control, phase control, constrained amplitude.