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Technico-economical analysis of a hybrid wave power-air compression storage system

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ABSTRACT

This paper presents a technico-economical analysis of a Pelamis wave power generator coupled with a proposed air compression storage system. Ocean wave measurements and forecasts are used from a site near the city of Saint-Pierre in Réunion island, France. The insular context requires both smoothing and forecast of the output power from the wave power system. The storage system is a solution to meet this requirement. Several power network services are defined by the utility operator in order to meet different load needs. The goal is to analyze the role of the proposed storage device for each desired network service. An optimization procedure, from previous works, based on available wave energy forecast, is used to compute the optimal storage size for each service. An economical analysis shows the feasibility from the addition of the storage device, as the hybrid source power output may be economically profitable compared to a raw wave power production.

1. Introduction

Integration of renewable energy sources in island networks are of great concern because of the absence of extended, robust and interconnected electric infrastructure. Mature and well established technologies, such as wind and solar power, are stochastic by nature, thus limiting the amount of “fatal” power available from these sources [1]. Energy storage systems are a solution to cope with the intermittent character of renewable sources. They are used to efficiently smooth power output and to store exceeding production. Ocean wave energy production technologies are also somewhat stochastic, with the design of the power take off (PTO) converter and its control being a crucial stage in a wave power generation project [2].

Within this context, the Seawatt R&D project was launched to develop a wave energy conversion farm with storage device units in the shores of Reunion island in the Indian Ocean (Lat. -21.34 Long. 55.43). The goal is to set-up an array of Pelamis P2 wave energy converters (WEC), for a total installed power of 30 MW at the selected site in Saint-Pierre (Pierrefonds) [3]. The Pelamis P2 units have 750 kW of rated power, composed by five tube sections linked by hinged joints (180 m long, 4 m diameter), and a conversion efficiency ~70% considering both thermodynamic and electrical circuits [2]. The selected site in Reunion island is a particular challenging problem since the ratio of renewable penetration (mostly PV) is close to a 30% limitation established by the utility operator, hence the importance of a storage device design.

In this paper, an optimization methodology for sizing of the storage device is presented. The storage size of the hybrid system is optimized to comply with desired performances for several network services defined by the utility operator. The optimization method presented in Ref. [1] is used to find a suitable storage size for each service. The method, based on the day ahead power production, relies on the quality of the forecast. This has been widely studied for storage sizing with wind power [4–6]. The optimization method is based on a general basic approach using minimum search.

As a part of the Seawatt project, the storage system is composed by an on-board air compression system, that will, in fact, work as an extension of the built-in power smooth storage device delivered with the Pelamis P2. The additional system takes advantage of the available empty space at each structure tube. However, only static

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Nomenclature

P_{bid}	Guaranteed power bid [kW]
P_f	Power forecast [kW]
P_{out}	Power output (from wave converter) [kW]
E_{out}	Energy output [kWh]
E_{lost}	Energy lost from P_{out} [%E_{out}]
P_{sto}	Storage power (P_{sto}>0 charge, P_{sto}<0 discharge) [kW]
P_{inj}	Power injected to the grid [kW]
P_{outinj}	Injected power part from P_{out} [kW]
P_{stoinj}	Injected power part from P_{sto} [kW]
P_{dev}	Deviation between output power and bid [kW]
$P_{min}{}^*$	Optimally guaranteed power [kW]
S/S^*	Useful/optimal storage capacity [kWh]
SOC	Storage state of charge [kWh]
P_c, P_d	Storage charge/discharge power [kW]
η_c, η_d	Storage charge/discharge efficiency [%]
DTR	Default time rate [%]
NPV	Net present value [€]
IRR	Internal rate of return [%]
FIT	Feed in tariff [€/MWh]

characteristics of the storage system are to be defined in this paper, as the assumptions made on the optimization method implies that the storage time constant is lower or equal to the considered time step Δt (1 h in this study).

A final step in the methodology is to analyze the economic benefit from the addition of the storage device. For this purpose, the guidelines presented in Ref. [7] are used.

2. Ocean data and wave converter power matrix

Wave data measurements from a chosen site near the city of Saint-Pierre (Pierrefonds) in Reunion island, France, are used. The available data include ocean state signals as significant wave height and maximum period of waves measured from 2000 to 2007 and 2009.

The optimization methodology presented in this paper is based on the day ahead output power bid computed from wave height forecasts. Available wave state forecast data from WW3 models are published by the US-NAVY at http://www.usgodae.org/. These forecasts include years 2005–present. For this reason, the base data set was chosen for the year 2006, for complete measured and forecast data. This is a limitation that may have an influence on the resource assessment analysis, hence the results presented in this article does not consider the inter-annual variability of wave energy. To account for inter-annual variations, it is recommended to consider at least 10 year of measured data.

The measured and forecast signals of the significant wave height and maximum period for the selected site in 2006 are shown in Fig. 1. Plotted data and spectral analysis of several years data shows a clearly seasonal behavior of the ocean state with particularly higher significant height and maximum period for the austral winter season.

With the forecast data, the power output of the Pelamis wave power converter can be computed using its power matrix. The Pelamis P2 power matrix, shown in Fig. 2, gives the correlation between the output power and significant height and maximum period of waves, it was developed in Ref. [3] using a regression on the simulation results obtained for various wave operating conditions using a non-linear wave to wire model of the converter. Using

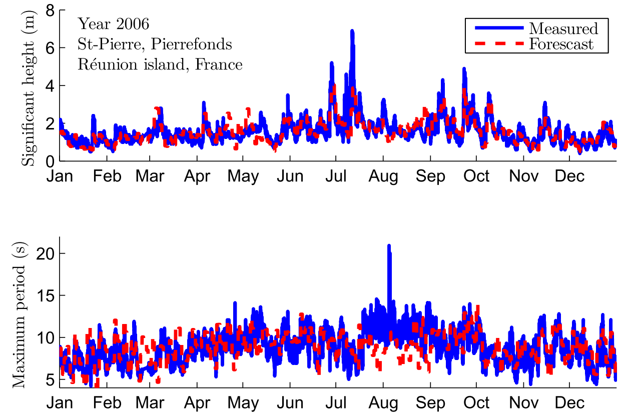

Fig. 1. Significant wave height and period in Pierrefonds, year 2006.

actual measured data and assuming an overall round trip efficiency of $\eta_{round} = 73.37\%$ ($\eta_{round} = \eta_c{}^*\eta_d$), the yearly mean value of effective power production P_{out} is 82.51 kW, roughly 11% of the 750 kW installed capacity for each converter, with maximum peaks at 667 kW (88.93% of installed capacity) during the winter season.

3. Network services

In this paper, several power network services are analyzed. These services are defined by the utility operator in order to cope with the different load needs. System services are presented in Fig. 3.

The first service S1, yields an hourly smoothed output of the day-ahead forecast power P_f. Service S2a1, comply with a bid of a yearly guaranteed constant power. Service S2a2, defines a bid of a constant power for each day of the year. Services S2b, S2c and S2d, defines bids within different time lapses for each day of the year. Specially service S2d is designed to provide a guaranteed power bid for evening peak hours. Finally services S4 and S5, defines combined bids of hourly smoothing and daily constant power with a constant power evening (18–22 h) service.

4. Methodology

4.1. Mathematical formulation

In this paper the storage is considered as a generic black box. The static technical characteristics of the storage system are

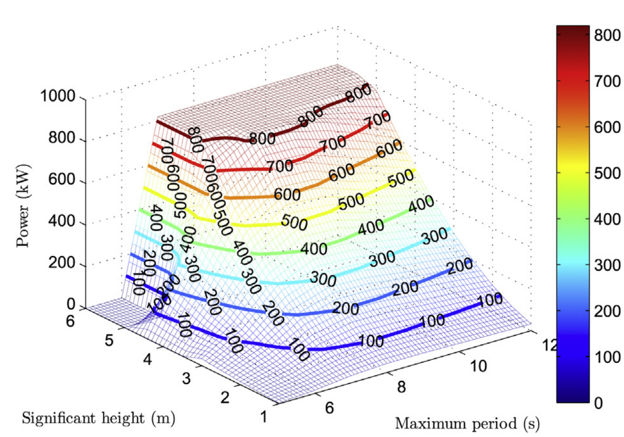

Fig. 2. Pelamis power matrix.