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Simulation of electricity supply of an Atlantic island by offshore wind turbines and wave energy converters associated with a medium scale local energy storage

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1 Introduction

Marine renewable like offshore wind turbines and wave energy devices will come to the market in a near future in Europe, pushed by the commitment of most of these countries to supply a large part of their energy by renewables in 2010. For such intermittent sources the coupling with a local energy storage is often necessary in order to regulate the energy output flow. This is a routine procedure when one deals with small scale installation of a few kW in isolated sites. It is less common in large scale plants of dozens of MW which are most often connected to the general network acting then as a storage of infinite capacity.

In this study we have evaluated by numerical simulations the benefit of coupling a medium scale electric storage to offshore wind turbines and wave energy converters, to supply the electricity to an island community. The simulations were performed by using real resource data (wind and waves) over a whole year (1999) and also the recorded data of the electricity demand of the island community.

We systematically varied the storage capacity, and the installed power at sea, considering three cases: offshore wind only, wave energy only, or a mixed solution combining these two resources. From our results we could predict the resulting flux of electricity between the island and the mainland. So, after this case study, we are able to size the energy storage depending on the energy management strategy chosen by the island community: self-sufficiency with regard to the utility network, or balancing the input and output electricity fluxes to a certain level, depending on economic parameters as kWh price, or any other choice.

2 The data

In this section we show the data used for this study: the electricity demand of the community and real resource data over one full year (1999). They concern Yeu island located off France west coast, near Nantes.

The top part of figure 4 depicts the electricity demand all over the year. About 5000 persons live here all year long, and the island population increases during summer holidays. That can explain why, the electricity demand is as important in summer and in April (Easter holiday) as in winter (when people needs heating). In this sample, the average annual power demand is about 4.16 MW and the peak power is 11.9 MW. This island is connected to the mainland network by submarine cables.

The top figure 1 shows the wind speed recorded at 55 m height. As expected, the velocity of the wind is higher in autumn and winter than in summer. The year average velocity is about 5.84 m/s and the maximal velocity is 24.3 m/s.

Medium and bottom figures 1 show respectively significant amplitude (H_s) and period (T_s) of the wave climate at a point few kilometers offshore Yeu island (data provided by LNHE). As expected, wave period and wave height are smaller in summer. As the wave power per meter width can be estimated by : $\text{power}=0.57*H_s^2*T_z$ kW/m (with $T_z = T_s/1.2$), the wave energetic resource is naturally smaller in summer. The year average incident wave power is about 25.8kW. For this site, the prevailing sea state is: $H_s = 1m$, $T_s = 10s$; the corresponding power per unit width being 4.75kW/m.

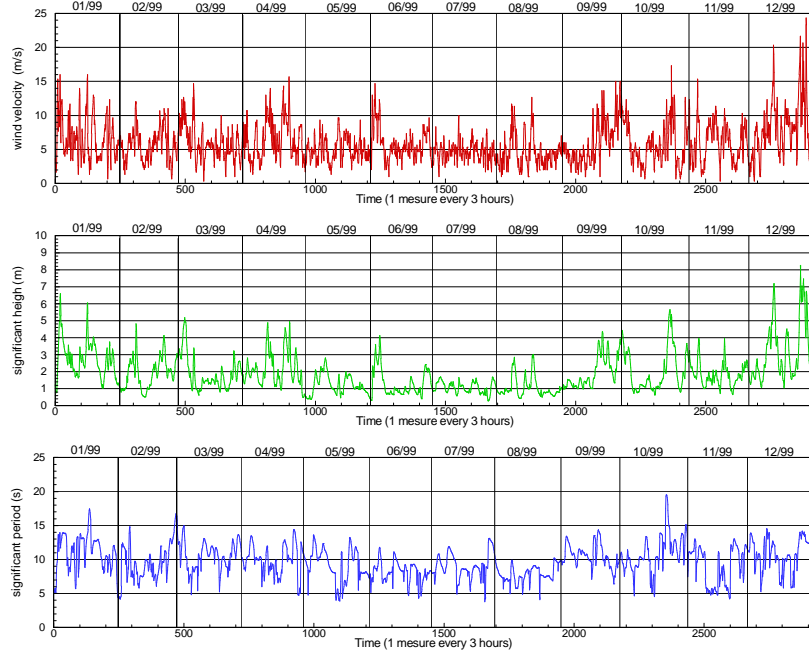


Figure 1: Time evolution of wind velocity (top), significant wave height (middle) and significant wave period (bottom)

3 Offshore energy generators

Wind and wave energy generators are modelled by simple basic models which are described below.

3.1 The wind turbine

In figure 2 the solid line shows the normalized power curve of a real device (from the manufacturer) and the dashed line is a simplified linear power curve used in this study. When the wind velocity is lower than 4m/s the turbine is considered to be stopped and the power output is zero. For wind velocity greater than 25m/s, the turbine is put in survival condition and the power is also set to zero. For velocity between 15m/s and 25m/s, the output power is the rated power of the turbine. In the simulations we worked with a normalized power curve not with a precise type of turbine, in order to vary the installed power of the virtual offshore park as a parameter. With this model of wind energy device and by using wind data depicted in previous section, a 10MW wind farm provides 21.52 GWh on this site. The predicted power output over the year is shown in the middle cell of figure 4.

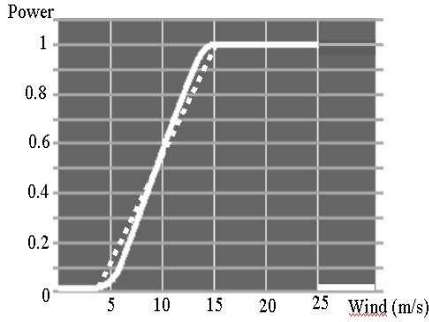


Figure 2: Wind turbine normalized power curve

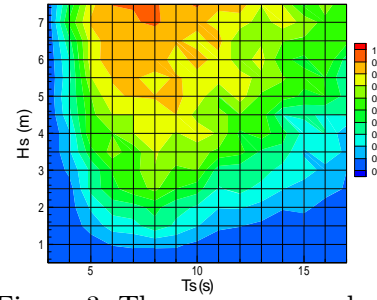


Figure 3: The wave energy device normalized power matrix.

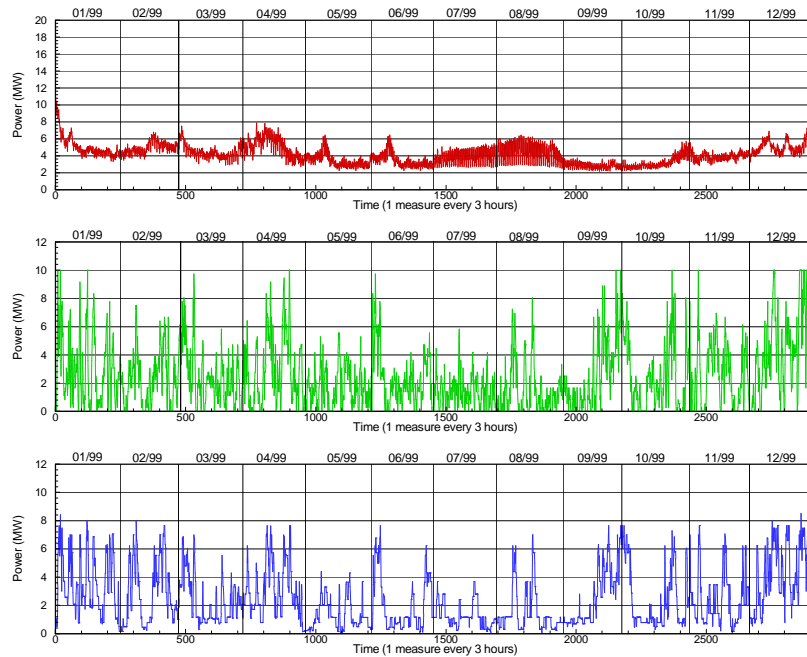


Figure 4: (top) electricity consumption; (middle) 10MW offshore wind farm production; (down) 10MW wave farm production.

3.2 The wave energy device

The wave energy device used here is a 250kW version of the SEAREV floating system, currently under development at ECN. Like the wind turbine power curve gives the power output for a given wind velocity, the average power matrix of a wave energy device (see Figure 3) allows to predict power output for each sea state characterized by two variables: (H_s, T_s) . Primary wave energy output being naturally fluctuating, we have to work here with average values. The average power output is generally lower than the installed power. To reduce the difference between average power and installed power, it is interesting to reduce the latter, which in turn increases the capacity factor. The maximal average power that the current device can provide is about 0.9 times the installed power. For the prevailing sea state, the normalized average power output is about 0.39.

With this model of wave energy device and by using wave data depicted in previous

part, a 10MW wave farm would deliver 21.42 GWh per year. The predicted power output over the year is shown in the bottom part of the figure 4.

3.3 The electricity storage and transmission lines models

In this study, we were primarily interested by the difference between the real dynamics of time domain consumption curves and offshore renewable energy production. So we keep a very basic modelling for the transmission and storage components. We have considered a perfect electricity storage model with no loss in input and output. This electricity storage is indeed unrealistic, but because our goal was only to compare different configurations, we consider this assumption as valid. We also supposed that transmission lines are perfect (no energy loss).

4 Results

Three configurations were considered for the electricity supply of the island: an offshore wind farm, a wave farm or a mix of those two sources. The installed power of each one and the storage capacity were the main parameters of the study. Left figure 5 shows the amount of energy exchanged yearly with the mainland: the island community imports energy when the offshore farms cannot provide enough energy, at the opposite when the amount of energy produced is larger than the demand, the community sells (export) excess energy to the mainland.

Let us first consider a configuration with no storage.

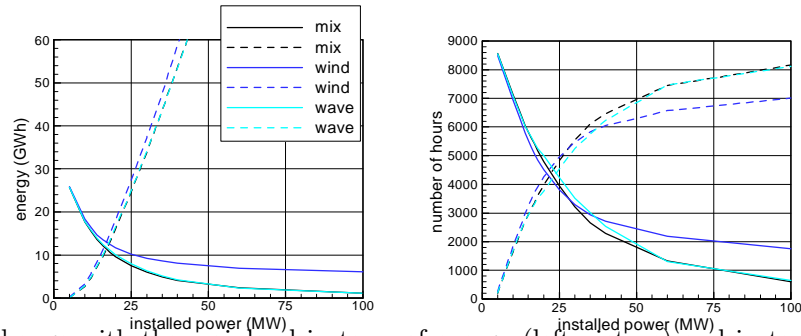


Figure 5: Exchange with the mainland in term of energy (left picture) and in term of number of hours (right picture). solid lines : the community buy; dashed lines : the community sell

We observe that curves corresponding to combined sources farm and wave farm are very close whatever the installed power. Whereas input and output energy fluxes are larger with wind generators, this difference increasing with installed power. Whatever the kind of farm used, the amount of sold and bought energy are almost equal when the installed power is around 17MW. A 17MW wave farm and a 17MW wind farm provide respectively 36.41GWh and 36.58GWh, which coincides to the energy consumed yearly (36.4GWh) by the island community. This first result confirms that it is not sensible to seek self-sufficiency from offshore renewables without using an intermediate energy storage.

The right part of figure 5 shows the number of hours when the community sells and buys energy to the network. The curves cross around an installed power of 22MW, which is a bit larger than the previous level of equal fluxes (17MW) for which energy importation

duration is larger than exportation duration. This is a consequence of the difference in the dynamics of electricity production from offshore sources and electricity consumption.

Let us now introduce an electricity storage and vary its capacity. The amount of exchanged energy will indeed decrease when increasing the latter, as shown on figure 6. For very small capacities, the wind farm curve slope is bigger than the two others, but when the capacity reaches 20MWh, the exchanges of energy are quite similar whatever the kind of farm installed. The amount of imported energy with combined wind and wave sources always remains smaller than the two others individually, as expected, but only of a few percent. This is a consequence of the high correlation between offshore wind and wave energy resources. For large storage capacity, amounts of exchanged energy become very close all together. Whatever the kind of renewable farm used it seems unrealistic to obtain electrical self-sufficiency of Yeu Island, with a reasonable installed power. With a 20MW farm, the self-sufficiency would be obtained with 760MWh storage capacity. Nevertheless it is easy for the community to reach a high level of autonomy: for example with a 22 MW farm (i.e: 5 times the averaged electrical power demand and twice the peak demand) and a 50MWh storage capacity (equivalent to 12 hours of averaged power), the community will need to buy about 5GWh (i.e: 14% of its yearly electrical consumption demand) and will be able to export three times as much as this amount of energy to the mainland network.

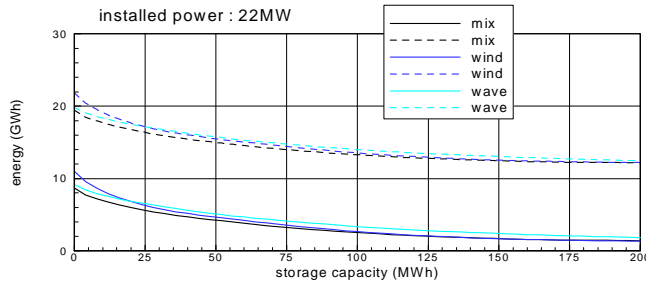


Figure 6: annual imported and exported energy fluxes (legend same as in previous fig.)

5 Conclusion

In this case study we have seen that the complementarity between offshore wind turbine and wave energy device is small due to the correlation between these sources. The level of energy delivered annually are very similar for the same rated power installed at sea. This is encouraging since the model of wave energy power matrix used here is a very preliminary version of the device that we are still optimizing. A third solar source would have been welcome to cope with the summer demand due to tourist rush in this area. Such a study has been undertaken.

It appears that full electrical self-sufficiency from offshore sources cannot be considered as a reasonable goal in the case of Yeu island. But we have shown that a high degree of energetic independence could be reached by associating to the offshore generators an electricity storage of reasonable capacity range. With such a configuration the ratio of exported over imported electricity could raise up to five or more. This should be accounted for in an economic study to be carried out now, but which was beyond the scope of the present study.

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