Increasing the rated power of existing wave test sites thanks to their electrothermal flexibility potential: a techno-economic feasibility study

C.H. Bonnard[1], A. Blavette[1], S. Bourguet[2], F. Rongère[3], T. Kovaltchouk[4] and T. Soulard[5]

[1]ENS Rennes, SATIE Lab., Dpt of Mechatronics., Fr., [2]Univ. Nantes, IREENA Lab., Fr., [3]now with D-ICE Engineering, Nantes, Fr. and was with Ecole Centrale de Nantes, Fr.,

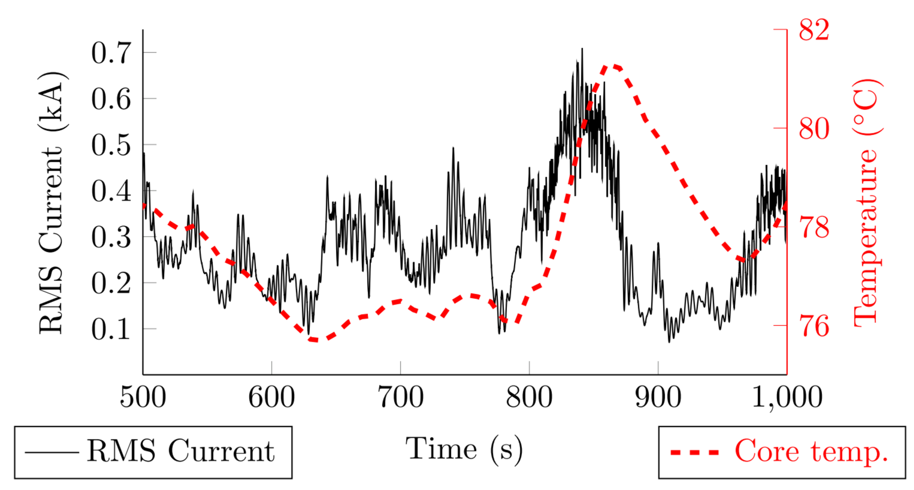
[4]now with the Lycée Roosevelt, Reims, Fr. and was with Univ. Rennes, CNRS, SATIE Lab., Fr., [5] Ecole Centrale de Nantes, LHEEA Lab., Fr

Abstract

Electrical power generated from sustainable energies, such as marine renewable energy (MRE), is a key to the future. However, the cost of production still remains higher than for conventional energy sources. This poster describes a preliminary techno-economic study about the energy production management of a modelled point absorber-based WEC farm that could be installed on the SEM-REV site, i.e. the French multi-technology open sea testing site. The two-fold approach presented in this paper relies on a wave to wire model of the farm coupled with an electro-thermal analysis of the SEM-REV export cable, and a simple WEC economic cost model. The proposed methodology, developed under Matlab-Simulink®, can be extended to other WEC types and more sophisticated models and control strategies. That makes it an interesting tool to determine the optimum number of WECs which can be added in an existing farm, as it depends highly on the sea climate of the future site, and in particular on its temporal characteristics. It is demonstrated in this paper that it could be feasible, from a techno-economic perspective, to increase the rated power of an existing WEC farm without requiring expensive grid reinforcements. This could be achieved by better exploiting the electro-thermal flexibility of its existing electric infrastructure.

Introduction

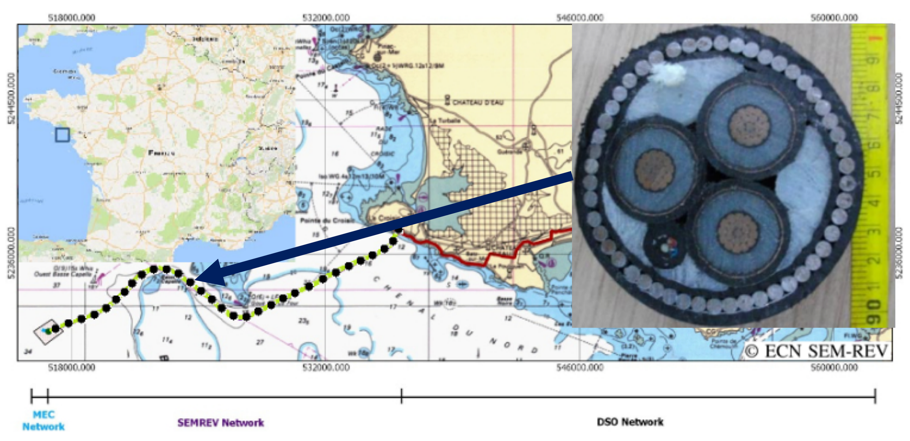
Considering the highly fluctuating power output of a wave farm composed of direct-drive point absorbers with little to no storage, one of our previous studies showed that a submarine power cable can carry, on a temporary basis, significantly more current than its rated value. Hence, it was proposed to consider thermal limits rather than current limits when monitoring the cable and operating a wave farm, as the latter may be quite irrelevant. We also considered economic aspects [1] in our approach to assess the optimal number of WECs.



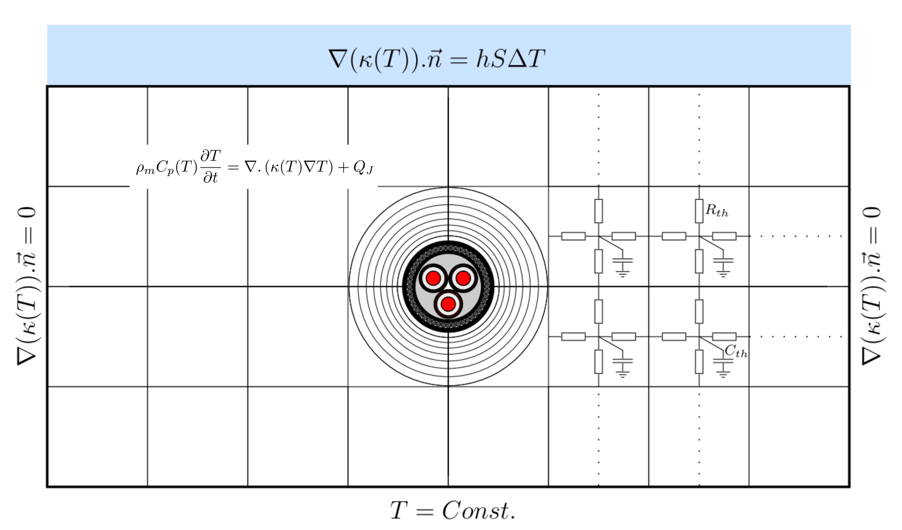
Example of a RMS current profile generated by a WEC farm composed of 20 WECs considering a Hs = 6 m and Tp = 9 s sea-state. The current profile is very fluctuating and ranges between 70 A and 700 A while in the same time the temperature varies only from 76°C to 81°C.

Materials and methodology

The SEM-REV open sea test site is located in western France, near Le Croisic, where the 24 km export cable used in this study is physically installed. It connects the SEM-REV offshore hub to an onshore substation and finally to the local network belonging to French DSO Enedis (red and dark green paths). Figure modified, courtesy of Ecole Centrale de Nantes [2].



A discrete model of the cable and of its direct environment as implemented under Matlab® where we used elements of different sizes (not to scale). The sea surface is not discretized in electro-thermal elements and we only considered a boundary condition for the heat transfer. The thermal equivalent electric circuits presented is composed of non-linear resistors Rth and capacitors Cth that are used to discretize the geometry.

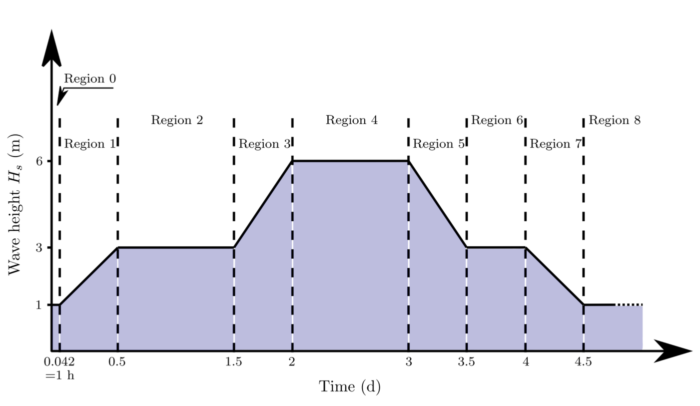


Sequence of sea-states that has been used for all simulation cases (see Table I). Note that it is a completely fictitious sequence but based on plausible durations and transitions between each sea-states based on [3].

TABLE I
DESCRIPTION OF THE SEA-STATE SEQUENCE+.

Region	Wave height H_s (m)	Duration (h)
0	1	1
1	1 to 3	12[a]
2	3	24
3	3 to 6	12[b]
4	6	24
5	6 to 3	12[b]
6	3	12
7	3 to 1	12[a]
8	1	12

+ The sea-states sequence is based on a single peak period T_p = 12 s, for all wave heights H_s.
b Increase or decrease by step of $\Delta H_s = 0.2$ m distributed uniformly over the region duration.
c Increase or decrease by step of $\Delta H_s = 0.25$ m distributed uniformly over the region duration.



Results

Three different scenarios are considered:

- Case 1 : The number of WEC is kept constant with $N_{WEC} = N^i_{WEC}$, where N^i_{WEC} corresponds to the maximum number of WECs which can be connected to the wave farm without exceeding the current carrying capacity, i.e.

$$max\left(I_{farm}(t)\right)|_{N_{WEC}} \leq I_{cc}$$

- Case 2 : The number of WEC is also kept constant with $N_{WEC} = N^+_{WEC}$. N^+_{WEC} corresponds to the maximum number of WECs which can be connected to the wave farm without exceeding the cable cores temperature constraints, i.e.

$$max\left(T_{core}(t)\right)|_{N_{WEC}} \leq T_{max}$$

- Case 3 : The number of WECs $N_{WEC} = N^v_{WEC}$ is allowed to vary between different sea-states. This can be achieved by (de)activating WECs between different sea-states, as mentioned earlier. However, the cable cores temperature constraints must still be satisfied, i.e.

$$max\left(T_{core}(t)\right)|_{N_{WEC}(t)} \leq T_{max}$$

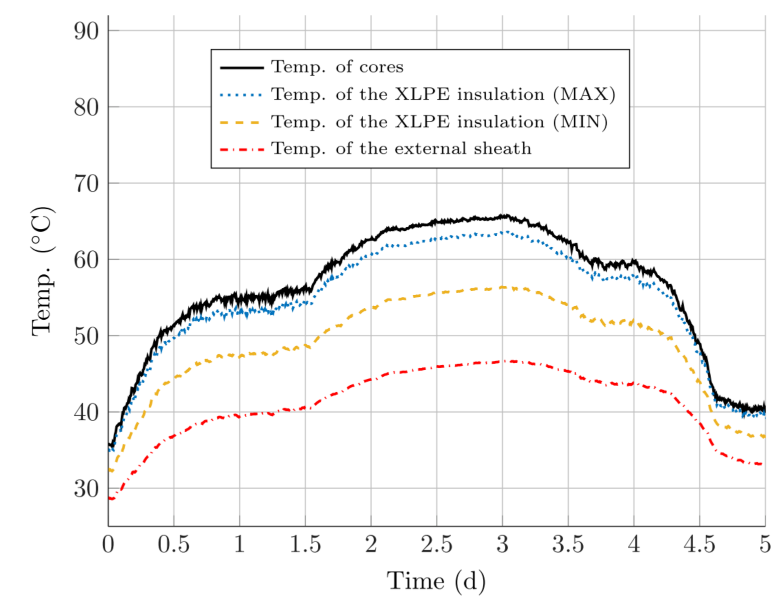
TABLE II
SUMMARY RESULTS OF CASE STUDIES

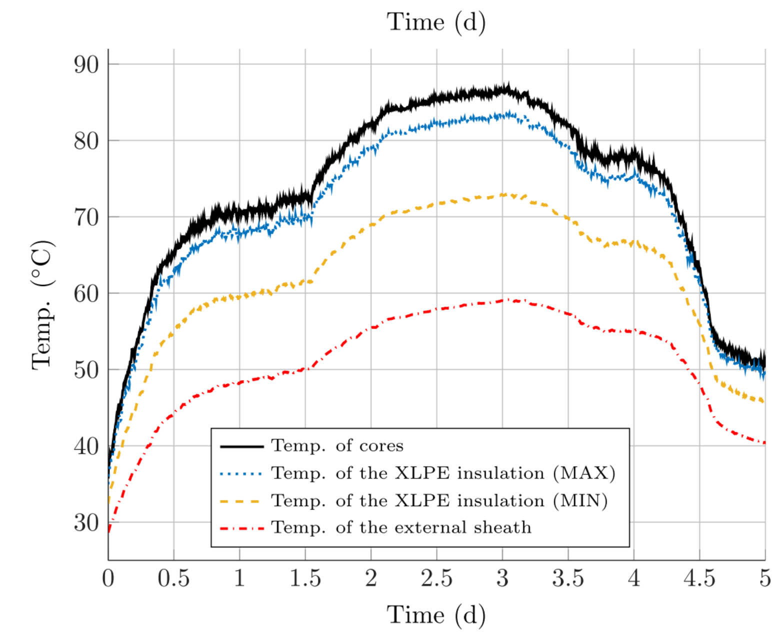
Case	N_{WEC}	Energy (MWh)	Gain [a]
1	11	1113	0% [b]
2	13	1315	+18.2%
3	13 to 25	1414	+27%

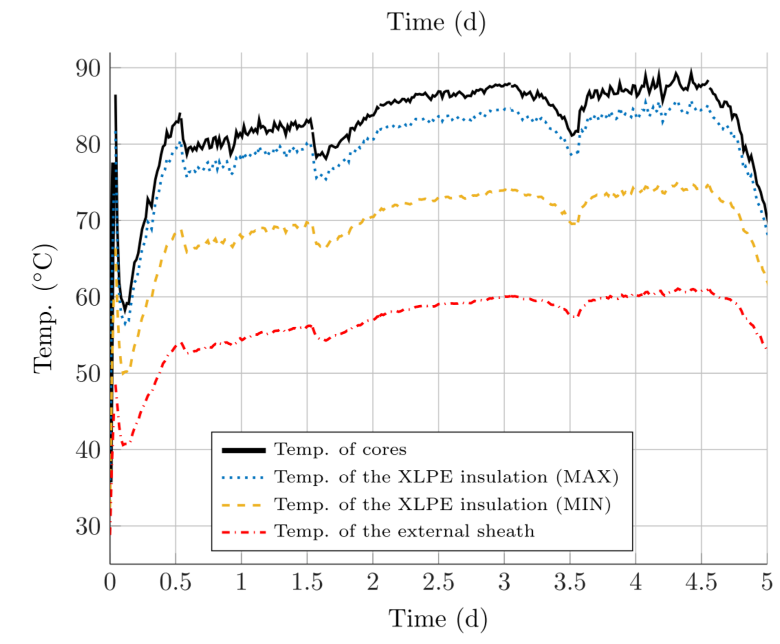
a Considering the sequence of sea-states given in Fig. 5 and neglecting the Region 0 that is irrelevant in Case 3.
b Considered as the reference case.

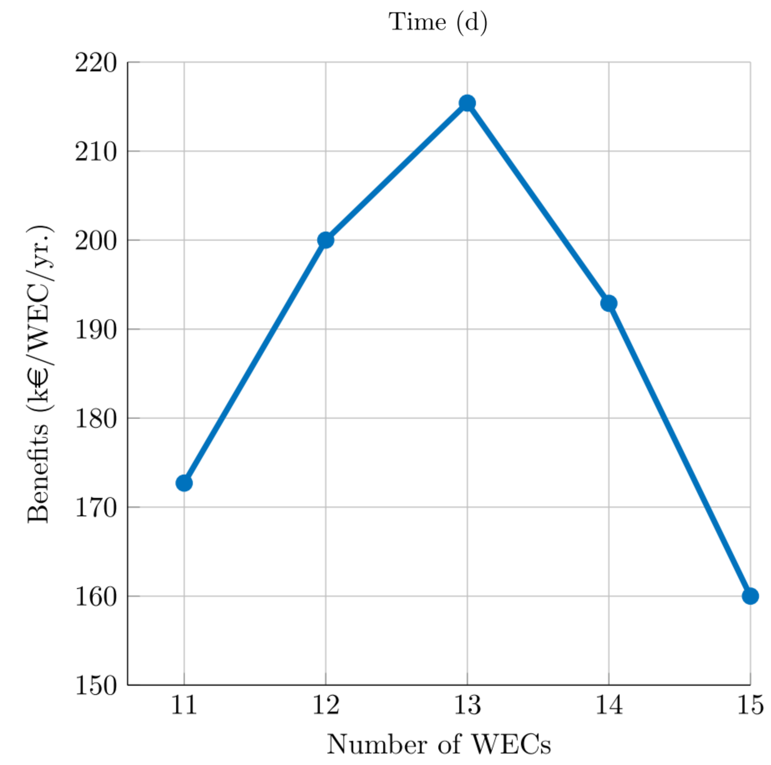
Assumed feed-in tarriff: 200€/MWh
➔ the 2025 targeted LCOE, as suggested by the European Commission for wave energy (see OES 2018 annual report).

Main findings:
- An optimal number of 2 additionnal WECs maximizes the benefits per WEC.
- Exploiting the thermal electro-flexibility of the existing farm may allow to increase its rated capacity of 18.2%, without grid reinforcements.









Conclusion and future work

The study described in this poster can be seen as a proof-of-concept analysis about the optimal use of an existing MRE farm. It focuses on the thermal response of the export cable to the fluctuating current of a wave farm in a sea-state sequence that considers different wave heights. It is shown that the combination of a wave farm fluctuating current and of the thermal inertia of the cable and of its direct environment, composed of the soil and of the sea, may allow an increase of the number of WECs, which could lead to an increase of the energy production of up to 27%. However, economic considerations lead to an optimal number of WEC that reduces the increase of energy production to 18.2 %, which maximizes the benefits per WEC. Future work will consider nearly a year of real sea-state data from the SEM-REV test site, which will allow us to perform a more comprehensive study with the use of a realistic and longer sea-state sequence.

Acknowledgments

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Further information

Contact : Charles-Henri.Bonnard@ENS-Rennes.fr and Anne.Blavette@ENS-Rennes.fr

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